Space Station Induced Environment Monitoring

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Space Station Induced Environment Monitoring

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Summary

In late 1987, a working group was formed to study the anticipated induced environment around Space Station. This working group is sponsored by the NASA Office of Space Science and Applications. The particular emphasis of this group is the induced neutral environment, the imbedded ion component, the emissions, the particulates, and the surface effects. The objective is to draw on existing expertise in gas phase and surface physics and chemistry in order to be able to develop an understanding of the nature of the complex coupled ambient--induced--surface environment of Space Station, and the processes likely to occur within this regime. In other words, if the induced neutral concentration could be modeled around the vehicle, the skills of this group could be used to predict the ionization, ultraviolet, visible and IR emissions, backscattered fluxes and chemical reactions, and to assess the impact of these on the scientific use of Space Station. The activities of the working group are closely coupled to a second group chaired by Dr. C. Purvis of the Lewis Research Center, which has addressed the induced plasma effects. The working group has met twice with somewhat different membership on each occasion, according to the topics to be discussed.

Induced Environment Modeling:

The first meeting was held at Hilton Head Island, South Carolina, on October 29-30, 1987. The main task of that meeting was to assess the knowledge available at that time and to attempt to use the expertise of the group to predict the likely induced environment in a variety of areas: neutrals, UV-VIS-IR emission, ions, particulates, and surface deposition. The objective of this exercise was to identify those parameters that were driving the uncertainty on the predictions and, in the case of areas of potentially significant contamination, to identify those parameters which, if quantified by theoretical or laboratory studies, would permit more accurate and useful predictions. As a result of this activity, it was determined that the scientific requirements in several areas would be marginally met. However, uncertainties on key parameters ranged over one to two orders of magnitude, and so it is possible that the actual environment might be considerably better or worse, depending on accurate values for such parameters as elastic and inelastic cross-sections. The group recommended certain studies that would result in a more precise quantification of several of these parameters. Details are given in the proceedings of the workshop which have been published as a NASA Conference Publication #3002.

Induced Environment Monitoring:

The working group met for the second time in Huntsville, Alabama on April 20-21, 1988. The list of participants is

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included in this document. In view of the potential impact of the environment on the ultimate utility of Space Station for scientific investigations, the major task of this meeting was to review current plans for monitoring the induced environment and to formulate the requirements for the principal elements of a package to monitor the induced neutral, emission, ion and particulate environment, together with surface contamination.

Towards this end, representatives from the Goddard Space Flight Center, Marshall Space Flight Center, and Johnson Space Center were invited to present the current plans for environmental monitoring in the various Space Station work packages.

The requirements for environmental monitoring (EM) are parts of four work packages (WP's): 1) MSFC, 2) JSC, 3) GSFC, and LeRC. The areas contained within a given work package are summarized in Figure 1. WP's 1, 2, and 3 have sections in their proposals addressing particulate and gaseous contamination. These sections deal in rather general terms with: 1) the development of a contamination measurement/monitoring package, 2) development of a contamination control plan, 3) the prediction of external contamination levels for comparison with contamination requirements, and 4) contamination related research/development activities. The details are sketchy at this time and in an early stage of definition. The participants agreed that the different WP responsibilities require coordination so that a uniform approach will result and costly duplication be avoided. The contamination measurement package envisioned by each WP center is limited mainly to one or more sets of different types of contamination measurement instruments aimed at the segment of Space Station specific to the particular work package. The additional task of integrating this package with other SS elements such as central power supply, operational control system, data system, other measurement packages, etc., needs to be addressed at Level II. Following this set of presentations, various participants presented their requirements for monitoring neutral gases, UV-VIS-IR emissions, particulates, and surface contamination. As a result of this exchange, it became apparent that there were several areas of overlap, and hence potential for optimization between these various interests.

A brief summary of the Induced Environment Monitoring Package (IMP) is as follows: The system should have sufficient capability to measure the major characteristics of the environment so as to:

1) determine the levels of the induced contaminants and the spatial/temporal behavior in a way that would verify the models
2) provide information on the fundamental nature of the environment and the processes taking place within it, in order to clarify our understanding of the phenomena involved.

The working group recommended a comprehensive monitoring package, including neutral and ion mass spectrometers, a particulate camera, an ultraviolet-visible and an IR spectrometer, and surface deposition monitors (QCMs and optical transmission/reflectance). A rough order-of-magnitude estimate of the resources required for this package is shown in Table 1. This primary package should be located on a pan/tilt mount.

In order to monitor the spatial variability, which is important to verify the models, smaller packages should be distributed at key locations on Space Station. It is suggested that there be approximately 4 of these secondary packages, the resources for which are summarized in Table 2.

While ideally the group would like to see two of the full-up IMPs, a great deal could be learned about the complex environment of Space Station with one full IMP and approximately 4 of the secondary IMPs. A rough estimate of the costs would put the comprehensive package at $12M with packaging and integration, and the smaller packages at $1M with packaging and integration. A microVAX/SPAN linked data system would require ~$3-4M to put in place and ~$0.5-1.0M a year to operate. The total program is therefore estimated at $19M plus ~1M a year to operate.

Details of the environment monitoring assessment are given in the papers contained in this document.

Contamination Requirements:

Another important task of this second workshop was to review several specific questions that had been raised concerning the Space Station contamination control document, JSC 30426. This activity started at a meeting convened in January 1987 by Science and Engineering Associates for the purpose of reviewing the requirements as stated in JSC 30426. As a result of that January 1987 meeting and the ongoing activities of this working group, several revisions had been suggested, and queries raised. The suggestions for modifications to JSC 30426 either proposed changes to existing paragraphs, or insertions for what is presently carried in the document as 'TBD', or proposed more general amplification to the document. In the light of the studies conducted by the working group so far, several of the suggested changes were recommended for incorporation. However, others were recommended for further study and quantification before they are reconsidered for inclusion in the requirements document. Unfortunately, because a number of the key parameters are poorly known or impact studies are yet to be done, the maturity of the assessment effort is lagging behind the Space Station need for requirements definition. Because of the potentially significant cost impact of some of the requirements, the working group decided to err on the side of the least impact to Space Station design, until concrete figures or conclusions could be provided. These items and their recommended dispositions are given in Section 2 of this document.

Conclusions:

Over the past year, significant progress has been made in establishing the boundaries of what is known about the likely induced environment of Space Station. Much of the value of the contributions that can be made by a working group such as this one, lies in its expertise in interpreting the coupled gas phase/surface and neutral/ion media that combine to make up the Space Station environment. These studies are in many cases based on 'best guesses' of certain fundamental physical parameters. It is strongly recommended that a number of specific and relatively small studies be conducted over the next two years to advance our ability to quantitatively predict this environment.

Monitoring of the actual Space Station environment is essential in order to appropriately use the platform for scientific purposes, and to possibly be alerted to any unanticipated deterioration of station systems. While it is not feasible to monitor all key locations of such a large system, one or more well-placed monitors in conjunction with comprehensive models will provide the necessary information. Coordination of the rather diverse efforts in this area would allow a better product for the available funds.

SPACE STATION PLAN
PHASE I

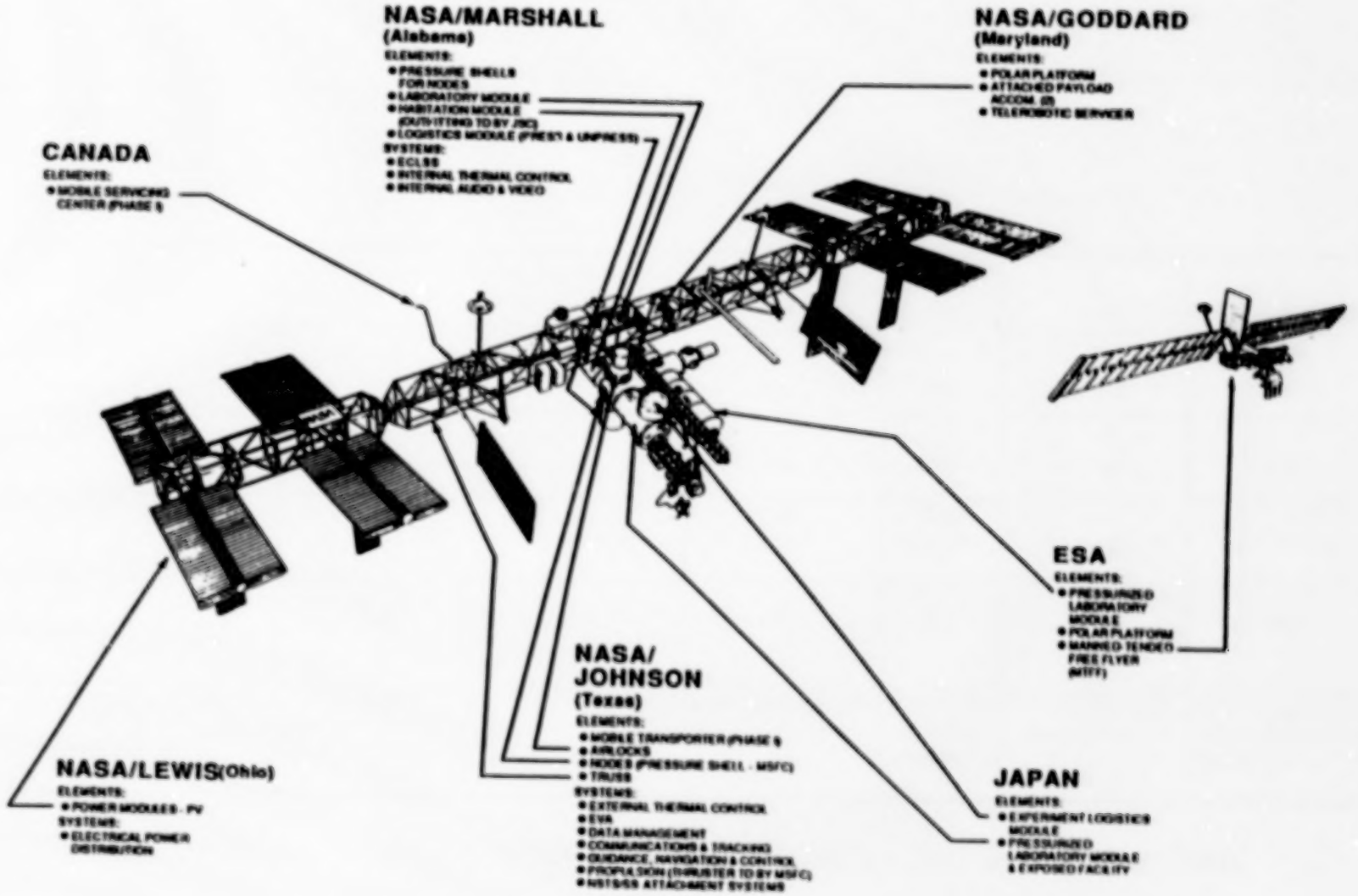

Figure 1

TABLE 1: INDUCED ENVIRONMENT MONITORING PACKAGE (IMP)

RESOURCE	NEUTRAL MASS SPECTROMETER	ION MASS SPECTROMETER	UV-VIS SPECTROMETER	IR SPECTROMETER	PARTI-CULATE CAMERA	SURFACE DEPOSITION	OPTICAL TRANSMISSION/ REFLECTANCE	TOTAL
MASS (KG)	10	10	12	125	20	3	10	170
DIMENSIONS (CM)	30 x 30 x 30	30 x 30 x 30	40 X 20 X 30	50 x 50 DIAM.	30 x 90 x 90	15 x 16 x 16	40 x 15 x 18	$1M^3$
POWER (WATTS)	15	15	30	160	100	20	15	325
DATA RATE (KBPS)	1	1	5	40	12	.02	.1	60
COST (M$)	3	1	.7	.55	.35	.15	.5	6

TABLE 2: SECONDARY MONITORING PACKAGES (SUB-IMPs)

RESOURCE	PRESSURE GAUGES	WITNESS PLATES	PHOTOMETERS (3)	QUARTZ CRYSTAL MONITORS	TOTAL
MASS (KG)	1	.5	3	3	7.5
DIMENSIONS (CM)	5 x 5 x 5	10 x 10 x 5	20 x 5 x 10	15 x 16 x 16	20 x 20 x 20
POWER (WATTS)	1	–	20	20	41
DATA RATE (KBPS)	0-1	–	1	1	2.5
COST (K$)	50K	20K	250K	120K	440K

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SUMMARY OF REQUIREMENTS IN NASA WORK PACKAGE #2

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Houston, Texas

Instrumentation

Work package #2 (WP2) has a section in the proposal dealing with measurements of the environment. Figure 1 summarizes the quantities to be measured as well as the instruments to be used. The information on Figure 1 provides only a cursory overview of what has been considered at the time of the proposal. Nevertheless it gives the general ideas and indicates that much work needs to be done to develop specifics. It is important to note that measurements in the field of particles and waves are not part of the proposal. On the other hand, some of the environmental measurements planned and included in the proposal do not fall within the category of contamination. Figure 2 shows some concepts of environment monitoring configurations.

Related Activities

Related activities which are presently pursued at JSC cover mainly three areas: 1) contamination level prediction, 2) measurement of the effect of high energy atomic oxygen on materials, and 3) preparations for the EOIM-3 STS flight experiment.

1) The MOLFLUX molecular flow model is being extensively used for trade studies concerning various contamination issues and combines all major Space Station structural elements and the Space Shuttle Orbiter. The model of the Space Station configuration will be updated as new data become available.

2) Efforts to measure the effects of high energy (5eV) atomic oxygen on various potential Space Station materials are continuing in cooperation with the Los Alamos National Laboratory. Because of the high energies involved, ground-based simulations of orbital effects have, until recently, been very difficult to achieve. A high-energy (5eV) atomic oxygen simulation facility using a CW laser-sustained discharge source is being developed to evaluate a wide range of materials and study the long-term effects of atomic oxygen exposure on typical materials used in Space Station applications. This facility produces a well-collimated beam of 1-5 eV oxygen atoms with fluxes of up to 10^{17} O-atoms/s-cm^2 by using a focused beam of laser energy to produce a high temperature, rare gas plasma in which molecular oxygen introduced upstream of the plasma discharge is dissociated into ground-state atomic oxygen. The reactions of atomic oxygen with Kapton, Teflon, silver, and various spacecraft coatings have recently been studied. The oxidation of Kapton has an activation energy of 0.8 Kcal/mole over a temperature range of 25°C to 100°C at a beam energy of 1.5 eV and produces low molecular weight, gas-phase reaction products (H_2O, CO, CO_2). Teflon has been found to react with ~ 0.1-0.2 efficiency to that of Kapton, and both surfaces show

a carpet-like appearance after exposure to the laboratory O-atom beam. Angular scattering distribution measurements of O-atoms off target surfaces show a near cosine distribution for reactive substrates, indicating complete energy accommodation of the energy with the target material. In comparison, non-reactive surfaces, such as nickel oxide, have shown specular-like scattering, with little accommodation (50%) of the translational energy with the surface.

3) Preparations for the EOIM-3 experiment are continuing. In addition to surface interaction studies, the beam facility at the Los Alamos National Laboratory is being used to calibrate a flight-qualified mass spectrometer for the EOIM-3 (Evaluation of Oxygen Interactions with Materials, third series) STS flight experiment. This experiment will study the interaction of materials with atomic oxygen in the LEO environment and is currently manifested on Space Shuttle mission 42, with launch to occur during July 1990.

SOME PRELIMINARY CONSIDERATIONS ENVIRONMENTAL MONITORING MEASUREMENTS AND INSTRUMENTS FOR WP-2

QUANTITY	INSTRUMENT
CONTAMINATION (Bid)	
Atomic Oxygen	Mass Spectrometer
Low MW Contaminants	Mass Spectrometer
Released Fluids	Mass Spectrometer
Released Fluids	Leak Detection System
Contam. Deposition (Wt.)	Quartz Microbalances
Contam. Optical Effects	Optical Effects Module
Heat Flux	Calorimeters
Pressure	Ionization Gauges
Released Particles	Camera(s)
PARTICLES AND WAVES (Not Bid)	
Particulate Radiation	Crew Dosimeters
"	Station Radn Monitors
Meteoroids and Debris	Not Defined
EMI	Spectrum Analyzers
Plasma	Ion Mass Spectrometer

FIGURE 1

ENVIRONMENTAL MONITOR CONFIGURATION

- **Several Concepts**
  - **Single Palletized Unit With Self-Contained Power and Data Recording, Locatable as Needed (Similar to IECM)**
  - **Single Palletized Unit, Linked to DMS for Power and Data I/O**
  - **Components From Pallet Individually Movable, Feeding Into Data Bus**
  - **Multiple Units, So That Environment Can Be Characterized in Several Places Simultaneously**
  - **Continuous or Intermittent Operation**
  - **Some Components will be Specifically Located at the Location Being Monitored (Dosimeters, Vibration Monitors)**

Figure 2

N89-15792

ENVIRONMENTAL MONITORING FOR SPACE STATION WP01

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ABSTRACT. External contamination monitoring instrumentation for the Space Station work package one (WP01) elements, were imposed on the contractor as deliverable hardware. The monitoring instrumentation proposed by the WP01 contractor in response to the contract requirement includes both real time measurements and passive samples. Real time measurement instrumentation consists of quartz crystal microbalances for molecular deposition, ion gauges for vacuum pressure levels, and a mass spectrometer for gaseous species identification. Internal environmental contamination monitoring for particuulates is included in both Lab and HAB modules. Passive samples consists of four sample mounting plates mounted external to the Space Station modules, two on the U.S. LAB, and two on the HAB module.

Introduction

Space Station work package (WP01) is defined as all Space Station hardware whose development is under the responsibility of Marshall Space Flight Center (MSFC). The contractor selected by MSFC for delivering the WP01 elements is Boeing Aerospace Company (BAC). Figure 1 is taken from the WP01 contract, all of the major elements to be delivered under this contract are identified in this figure. These elements consist of the HAB module or living quarters, U.S. LAB or experimental laboratory for scientific investigations in the low gravity environment, four resource nodes for both docking and interconnnecting the various modules, and the LOG or logistics modules both pressureized (3 units) and unpressurized (2 units) for resupply of fluids, gases, and experimental instrumentation.

Requirements

Environmental monitoring requirements for the Space Station are defined in "Space Station External Contamination Control Requirements" JSC 30426. These requirements were imposed on the WP01 element contractor. Not only must the contractor provide monitoring instrumentation as part of the WP01 elements, but these elements must meet the contamination control requirements for Space Station. This means that the WP01 elements in themselves cannot be a source of contamination to a level that exceeds JSC 30426. Potential sources of contamination of the

WP01 elements include venting, thruster firings, leaks, and material offgasing. All of these sources are controlled by imposing on the WP01 contractor specific contamination control requirements. The contractor must prepare and submit a document defining how he plans to meet the requirements defined in JSC 30426 which when reviewed and approved by MSFC becomes the controlling document for the WP01 elements. This document "Contamination Control and Implementation Plan" (CCIP) D683-10126-1 has been prepared by BAC and is in the approval cycle. The CCIP covers the time period from design, through orbital operations. Materials selected must meet stringent outgasing criteria based on JSC SP-R-0022 (VCM) for vacuum compatability, and offgasing criteria based on NASA NHB 8060.1B for toxicity and flamability control. Normally all materials must meet the VCM criteria of <0.1% of the original mass at 125 °C, under hard vacuum; but in special cases when contamination sensitive optical surfaces will be directly exposed to these materials, more stringent testing is required. This more stringent testing requires that the material under question be exposed to optical witness samples identical to the flight optics, under simulated flight conditions of vacuum and temperature to verify that the optical surfaces will not be degraded by offgasing products.

Cleanliness control during fabrication must be maintained in order to deliver hardware meeting stringent surface cleanliness levels of 750 per MIL-STD-1246A for particulate and a non-volatile residue (NVR) level of <2 mg/ft^2. Hardware surfaces must be measured at various locations to verify they meet the above criteria. In addition, environmental controls along with monitoring are imposed to maintain cleanliness levels during all ground operations.

During orbital operations contamination via overboard venting is controlled by permitting only gaseous venting; and then only to the extent that the molecular column density limits in JSC 30426 are not exceeded. The other main source of contamination during orbital operations is thruster firings for station reboost and Shuttle or other vehicle docking operations. Nozzle designs for reboost thrusters are such as to minimize backflow, but still the contamination limits will probably be exceeded. These time periods during docking and reboost are designated as "nonquiescent periods" and will be unacceptable times for many experiments. After the nonquiescent periods are over the quiescent periods will be re-established for experiment observations.

Baseline Monitoring Instrumentation

Environmental monitoring instrumentation as proposed in the WP01 contract is described in Figure 2. This figure was taken directly from the Boeing contract proposal. Contamination detection instrumentation consists of the last five items at bottom of the figure. Other monitoring instruments are included

in the figure and grouped together are designated as "Special Performance Instrumentation". Internal contamination environment of the modules will be monitored for particulates and molecular levels. Particulates will be measured using standard clean room type instrumentation modified for manned flight. One instrument will be located in the U.S. LAB and one in the HAB module. In addition one spare particle counter has been identified. Molecular contamination data can be obtained from the gas analyzer in the life support system (ECLS).

External contaminatin environment will be monitored to verify that the WP01 elements do not exceed their alloted contamination levels; and detect if, when, and to what extent other Space Station elements contaminate the WP01 module element radiators, windows, or other sensitive surfaces. LAB module venting from experiments or from the ECLS, including the seal leakages must be monitored and warnings issued to protect exposed sensitive experimental instruments when contamination limits are approached. Space Station reboost operations and all docking operations where thruster firings are required must also be monitored closely. If excessive contamination deposition occurs during these events, the magnitude of the contaminate deposition in terms of mg/cm^2 will be obtained with the quartz crystal microbalance (QCM) on a real time basis with sensor response times within one second.

Identification and concentration of contaminants in the gas phase in the immediate vicinity of the modules will be obtained with the mass spectrometer and ion gauge. Optical property effects on exposed surfaces to contamination will be determined from the "particle fallout" plates which are really sample plates exposing selected witness samples having surfaces sensitive to contaminatin such as thermal control coatings, window material, radiator coatings, and optical witness mirrors. These samples can be retrieved and returned to ground laboratories for detailed analysis, to determine the extent to which the actual orbital hardware surfaces have been degraded and to institute corrective actions as requried.

The instrumentation briefly described above represents the WP01 baseline contamination monitoring hardware to be delivered by the contractor (BAC). Additional monitoring instrumentation is listed in Figure 2 which will provide data for other than the contamination environment and is included to provide a better overview of the available (planned) instrumentation. It should be noted that all of this instrumentation is subject to Space Station Project review and could be reduced to meet funding limitations.

Additional Monitoring Instrumentation

One problem with the instrumentation to be provided is the lack of the real-time or inflight optical property measurements. The only direct data will be provided by the passive samples on the "partial fallout" plate which must be removed and returned to the ground laboratory for measurements. The time response for determining the level of contamination damage is at least several days. In addition the transportation environment from orbit to the ground laboratory will change the damage level on thermal control surfaces and could even effect optical mirror damage levels. Also, it is extremely difficult except in ideal situations of determining optical degradation from indirect data such as mass deposition levels. For all of the above reasons several flight instruments have been developed at MSFC to provide this missing information using real-time inflight measurements.

Data as to degradation in the vacuum ultraviolet region for specular type optics can be obtained using the "Automatic Contamination Evaluator" (ACE). This instrument was developed under the SBIR program by ARC, Inc. An operational schematic describing the functional layout is provided in Figure 3. Wavelength range is from 120 nm to 220 nm. Different wavelength ranges can be obtained by selecting different gratings, detectors, and/or light sources. A prototype flight unit has been delivered to MSFC and is undergoing operational evaluation in a space environmental simulation vacuum chamber. Optical data taken with the ACE and with standard laboratory vacuum ultraviolet reflectance and transmission instruments agree within 2%.

In the visible wavelength region two similar instruments could be utilized. One is now flying on the LDEF, and scheduled to be returned by the Shuttle late next year. This instrument is the "Thermal Control Surfaces Experiment" (TCSE), which can measure total hemispherical reflectance of coatings on a sample wheel. A schematic drawing is provided in Figure 4. An advanced version of this instrument is in the definition stage of development, under the NASA Outreach program. The advanced version is designated as the "Optical Properties Module" (OPM), and includes the additional capability to measure the total diffuse scatter of coatings throughout the visible wavelength range (220 nm to 2500 nm).

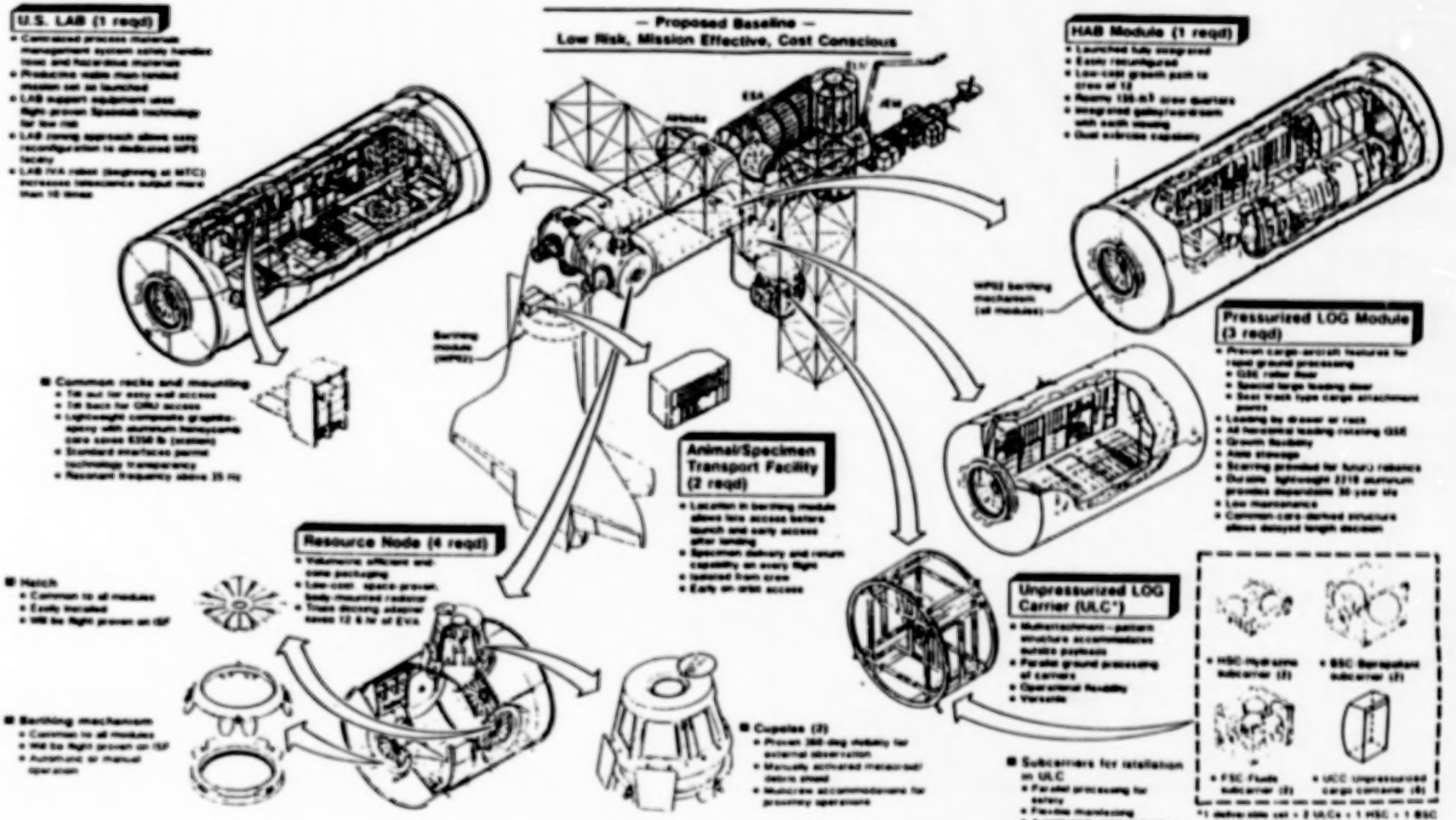
— Proposed Baseline —
Low Risk, Mission Effective, Cost Conscious
U.S. LAB (1 reqd)
HAB Module (1 reqd)
Pressurized LOG Module (3 reqd)
Animal/Specimen Transport Facility (2 reqd)
Resource Node (4 reqd)
Unpressurized LOG Carrier (ULC*)
Common racks and mounting
Hatch
Berthing mechanism
Cupolas (2)
Subcarriers for installation on ULC
HSC Hydrome subcarrier (2)
BSC Specialized subcarrier (2)
FSC Fluids subcarrier (2)
UCC Unpressurized cargo carriers (8)
*1 deliverable unit = 2 ULCs + 1 HSC + 1 BSC + 1 FSC + 4 UCCs (2 sets reqd)
WP01 Proposed Baseline

FIGURE 1

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Instrumentation description		Unit weight, lb	Unit size, in³	Unit average power, W	Design maturity	Make-or-buy GFE	US LAB	HAB	Number required							Airlock	Spares	Location
									Logistics		Nodes							
Measurement type	Measurement method								Pres	Unpr	1	2	3	4				
Safety/structures																		
• Internal pressure monitor[a]	Pressure transducer	0.2	1.3	0.0	O	B	2	2	2	0	2	2	2	2	0	2	S, I, E
• Structural expansion monitor	Strain gauge	0.1	0.1	0.0	O	B	10	10	10	10	5	5	5	5	0	2	I/E
• Thermographic monitor	Thermographic scanner	3.8	329.9	0.2	N	B	1	1	0	0	0	0	0	0	0	0	E
• Internal acoustics monitor[b]	Piezoelectric crystal	1.9	90.2	0.0	M	B	1	1	1	0	0	0	0	0	0	1	I
• Pressure shell acoustics monitor	Piezoelectric crystal	0.2	1.2	0.0	M	B	4	4	4	0	4	4	4	4	0	2	I
	Preamplifier	0.3	18.9	2.0	M	B	4	4	4	0	4	4	4	4	0	2	I
• Rack latch position indicator	Switch	0.1	0.1	0.0	O	B	44	44	12	0	0	0	0	0	0	2	I
• External mechanism connection indicator[c]	Switch	0.1	0.1	0.0	O	B	2	2	2	4	8	8	8	8	2	2	E
Radiation detection and Monitoring																		
• Structural current monitor[d]	Current probe	0.2	1.2	0.0	M	B	10	10	5	5	2	2	2	2	2	1	I/E
• Ionizing radiation detector	Scintillation counter	1.2	300.5	5.0	O	B	2	2	1	1	1	1	1	1	0	1	I
• Static charge monitor	Voltage probe	1.1	4.9	0.3	M	B	8	8	4	4	4	4	4	4	0	2	I/E
• Power transient monitor[e]	Current probe	0.9	1.2	0.0	N	B	4	4	1	0	0	0	0	0	0	1	I
• Plasma detection monitor	Ionization detector	15.2	300.5	23.1	N	B	1	1	0	0	0	0	0	0	0	1	I
• Electric field monitor	Antenna	1.1	4.9	0.0	M	B	3	2	1	1	1	1	1	1	0	1	E
Trend/verification																		
• Incipient failure device monitor[f]	Piezoelectric crystal	0.1	1.2	0.0	M	B	10	10	2	0	2	2	2	2	2	2	I
	Preamplifier	0.3	1.2	2.0	M	B	10	10	2	0	2	2	2	2	2	2	I
Contamination detection																		
• Particle fallout	Sample plates	0.3	9.0	0.0	N	B	2	2	0	0	0	0	0	0	0	1	E
• Particle environment	Particle counter	54.4	875.0	8.3	M	B	1	1	0	0	0	0	0	0	0	0	I
• Molecular deposition	Quartz crystal microbalance	3.0	11.0	1.5	O	B	2	2	0	0	0	0	0	0	0	0	E
• Pressure	Ion gauge	0.5	137.6	1.8	M	B	2	2	0	0	0	0	0	0	0	1	E
• Species[g]	Mass spectrometer	52.6	925.0	9.0	M	B	0	1	0	0	0	0	0	0	0	0	E
							Weight, lb		115.7	167.2	16.4	9.2	11.9	11.9	11.9	11.9	1.4	26.4	
							Volume, ft³		1.6	2.1	0.3	.2	0.2	0.2	0.2	0.2	0.1	0.5	
							Avg power, W		78.5	87.5	18.2	87.5	18.2	18.2	18.2	18.2	4.0	0.0	

[a] Redundant device
[b] Portable unit, rechargeable battery
[c] Indicates positive connection (umbilicals, berthing, hatches)
[d] Measures circulating current in structure
[e] One per PDCU, power (EPS, WP04)
[f] Criticality 1 rotating devices
[g] ECLSS LAB mass spectrometer will be used in LAB

All signal conditioning will be in sensor or MDM, preamplifier/signal conditioner power supplied by MDM

Legend:
S Shell
I Internal
E External

FIGURE 2 *Special Performance Instrumentation*

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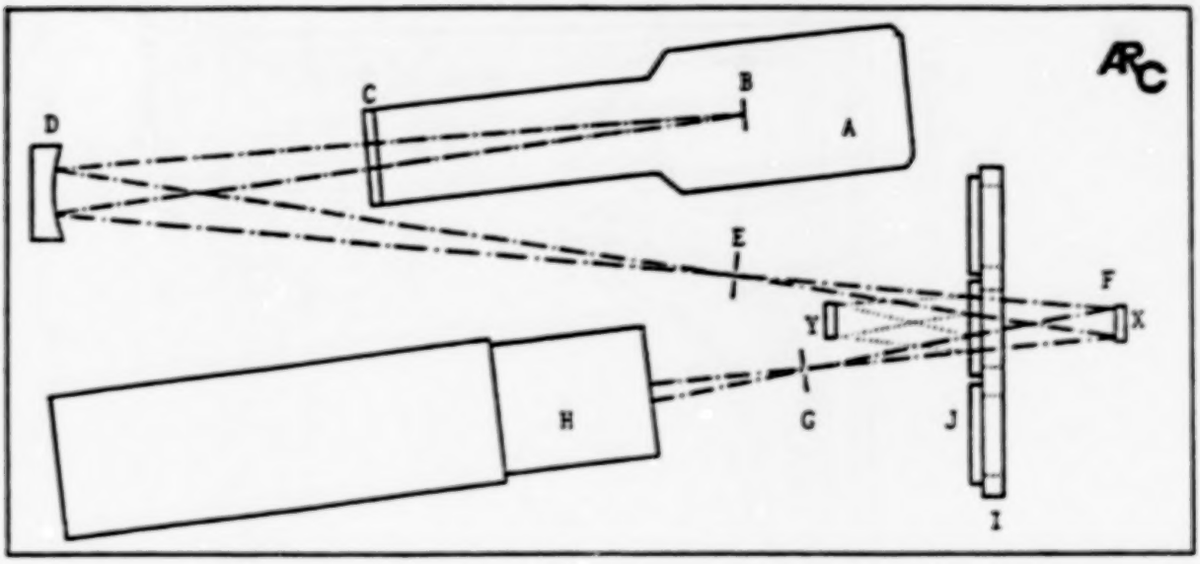
ACE OPTICAL SYSTEM



A. Light Source

B. 1mm Diameter Entrance Aperture

C. MgF2 Window

D. Holographic Grating, 1800 g/mm, 200mm concave radius

E. 1mm Exit Aperture

F. Indexable Concave "Mode Mirror"

G. Light Baffle

H. Solar Blind Detector

I. Sample Wheel

J. Sample

X. 100% Baseline, and Transmittance Measurement Position

Y. Reflectance Measurement Position

FIGURE 3

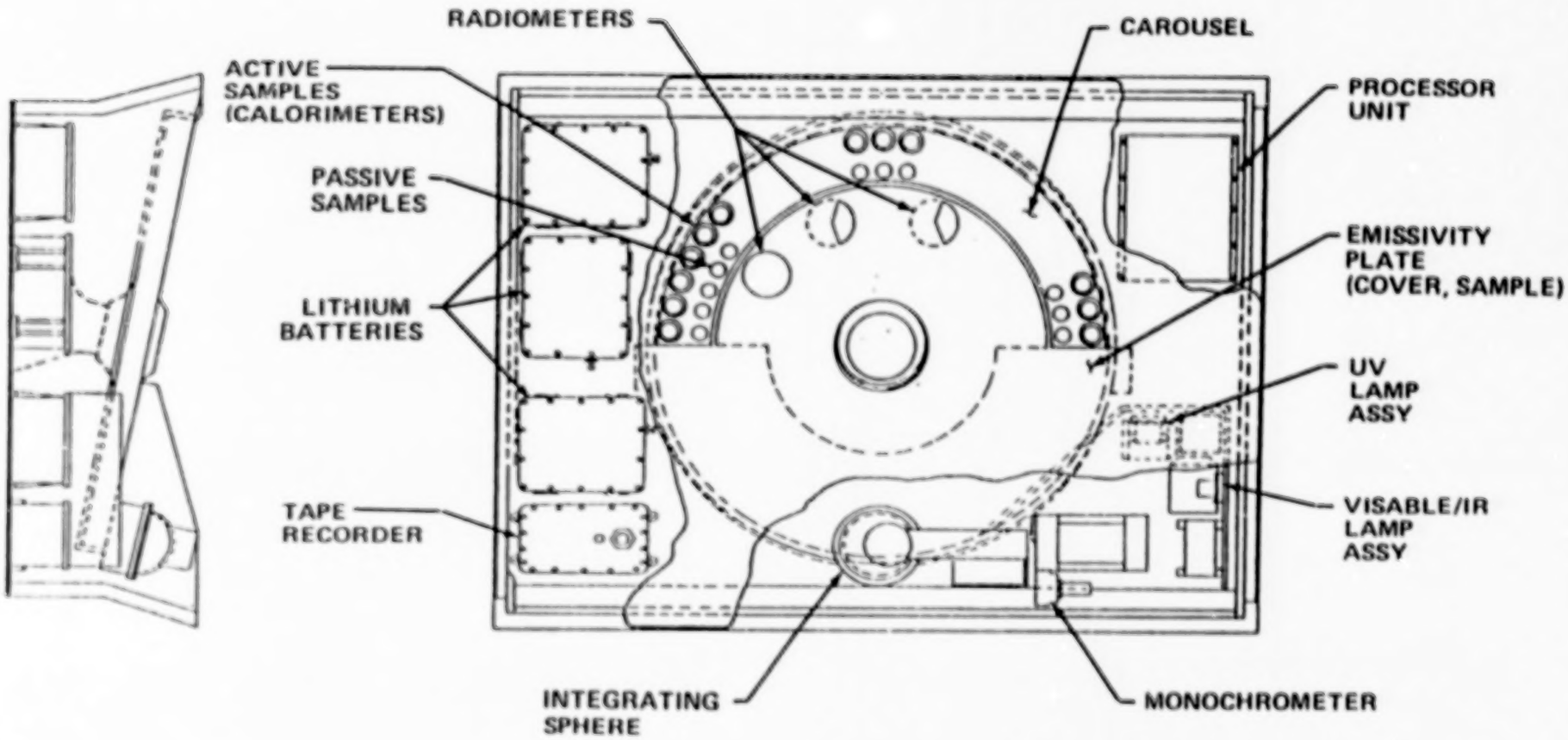


FIGURE 4 – Thermal Control Surfaces Experiment Assembly

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N89-15793

GSFC CONTAMINATION MONITORS FOR SPACE STATION

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ABSTRACT. This paper describes the Work Package 3 activities in the area of neutral contamination monitoring for the Space Station. Goddard Space Flight Center's responsibilities include the development of the Attached Payload Accommodations Equipment (APAE), the Polar Orbiting Platform (POP), and the Flight Telerobotic Servicer (FTS). GSFC will also develop the Customer Servicing Facility (CSF) in Phase II of the Space Station.

INTRODUCTION

The Work Package 3 Contamination Monitoring System (CMS) includes monitors for the APAE, the POP, and the CSF. Information has been gathered on contamination requirements and sensitivities of candidate payloads. Typical spacecraft have been modeled to evaluate the effects of the Space Station environment on payload performance, and to support the definition of the CMS conceptual design. Based upon these activities, several contamination monitoring candidates have been identified. Furthermore, we have established tentative monitoring locations for science payloads on the Phase I Space Station.

REQUIREMENTS

The RFP for Work Package 3 states several requirements for the sensitivities of the contamination monitors. For total pressure, the requirement is to measure in the range of 2×10^{-10} to 2×10^{-3} Torr. Ionization gauges of the Bayard-Alpert design were tentatively selected to monitor this quantity. For molecular deposition on sensitive surfaces, the required sensitivity is 4.4×10^{-9} g/cm^2/Hz. Quartz crystal microbalances (QCMs) will serve as real-time monitors of molecular deposition. Deposition of particulates must be monitored with a sensitivity of 3.5×10^{-9} g/cm^2/Hz. A "sticky QCM" with an oil coating on the sensing crystal has been proposed for this measurement. For molecular species in the field of view, monitors must be sensitive to partial pressures of 8×10^{-11} to 8×10^{-4} Torr for individual species from 1 to 150 amu. Mass spectrometers were selected to monitor column densities. Remote sensing of particles in the field of view is a technology currently under development. For example, the goal of current Goddard SBIRs is to produce remote particle detectors.

CMS DESIGN DRIVERS

1. USES

There are two primary uses planned for the Work Package 3 contamination monitoring system and the data it collects. One is to verify that the Space Station external environment meets the contamination requirements, as expressed in JSC 30426, the "Space Station External Contamination Requirements Document." Second, as specified in the RFP, the CMS is to act as a warning system for attached science payloads, alerting for appropriate action in the event of high contamination levels.

The CMS may have other secondary roles currently not included in the CMS design: 1) to correlate payload throughput with measured contamination levels; 2) to use the CMS to gather environmental data and compile a data base; and 3) to verify existing computer contamination models.

2. SPACE STATION EXTERNAL CONTAMINATION REQUIREMENTS

The requirements for external contamination levels are stated in JSC 30426, and are summarized in Table 1. A number of suggested changes to the requirements are currently being reviewed by the appropriate working groups.

Table 1. Space Station External Contamination Requirements

Molecular Column Density (molecules/cm^2)	IR emitting: 10^{11}/species, total 3 10^{11} all others: 10^{13}/species, total 5 10^{13}
Molecular Deposition ($g/cm^2 sec$)	300 K, 2 sr FOV: 10^{-16} 300 K, 0.1 sr FOV: 10^{-14} 5 K, 0.1 sr FOV: 2 10^{-13}
Particulates in FOV	> 5 micron diam: 1 particle/orbit/10^{-5}sr < 5 micron diam: TBD
Particulate deposition	TBD

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Table 3. Space Station Material Outgassing Rates

Element	Potential Problem	Contam. rate ($g/cm^2 sec$)
Truss	Water outgassing:	
	Uncoated graphite/epoxy	10^{-9}
	Gr/ep + vapor-dep. coating	10^{-12}
	Gr/ep + Al foil coating	none
Solar arrays	Outgassing:	
	95°C	10^{-9}
	30°C	$7 \cdot 10^{-12}$
Thermal blankets	Water outgassing:	
	Initial rate @ 25°C	10^{-9}
	25°C, after 100 hours	10^{-13}
Heat pipes	Ammonia leakage/diffusion	10^{-9} to 10^{-8}
Manned modules	Venting	$6 \cdot 10^{-4}$ g/sec
Attitude control thrusters (O_2/H_2)	Effluent:	
	Forward flow	10^{-5}
	Backflow	10^{-9}
	Residual cloud	10^{-10}
Shuttle PRCS thrusters ($MMH-N_2O_4$)	Forward flow effluent	10^{-5} to 10^{-4}

Table 4. Contamination Monitors Studied

Instrument	Manufacturer or source of data	Range	Sensitivity
Quadrupole mass spec	Air Force Geophysics Lab	1-150 amu	30-50 (M/ΔM)
Mattauch-Herzog mass spec	K. Mauersberger, U. of Minnesota	50 masses mass. simultaneously	200 (M/ΔM)
Bayard-Alpert ionization gauge	Leybold-Heraeus	10^{-10} to 10^{-2} torr	1 %
TQCM	QCM research	10^{-5} g/cm^2	$1.6 \cdot 10^{-9}$ g/cm^{2}Hz
Oil-coated QCM	Faraday labs	10^{-5} g/cm^2	$1.6 \cdot 10^{-9}$ g/cm^{2}Hz
FOV partic. monitor	Miranda labs	1 meter sensing region	1 particle > 5 micron diam.

3. USER REQUIREMENTS

The monitoring system sensitivity must be compatible with the set of user requirements. Table 2 is a compilation of the most current user requirements for Attached Payloads.

Table 2. Space Station Attached Payload User Requirements

Payload	Contamination Sensitivities
Heavy Nuclei Collector	none
Diffuse X-ray Spectrometer	H_2O, deposition < 3 g/cm^2 on crystal panels
Cosmic Dust Collection Facility	all particulates, micrometeoroids, debris
Tropical Regions Imaging Spect.	dep. on optics, H_2O & CO_2 in FOV
Tropical Rainfall Mapping Miss.	unknown
Earth Radiation Budget Expt.	H_2O in FOV
Solar-Terrestrial Observatory	molec. dep, molec. FOV, partic. FOV, warning
LAMAR	partic. in FOV
Cosmic Ray Nuclei Experiment	none
Search & Rescue Interferometer	unknown
Astromag	none
X-ray telescope	dep. cause <10% change in optical properties
X-ray polarimeter	unknown
Active Galactic Nuclei	molec dep <10 Å, col. den. <10^{13} molec/cm^2
All sky monitor	none
Burst & transient monitor	UV-active molec dep & FOV, partic dep & FOV
High energy background expt.	avoid sun, can't observe into RAM
Astrometric telescope	dep <100 Å/yr, col. den. <10^{13}, need warning

4. EXPECTED ENVIRONMENT

Table 3 summarizes outgassing rates for various Space Station materials. This type of information can be used as input for the computer models to assess the Space Station external environment and its effects on both the payloads and the Space Station itself. The CMS design process also benefits from these activities. The identification and characterization of sources is a critical activity, which must and will continue through all the phases of the system design.

5. TECHNOLOGY READINESS

Another major influence on the design of the CMS is the availability of the selected monitors for space flight. Table 4

shows some of the instruments that have been considered. Of these, the quadrupole mass spectrometer and the TQCM have been previously flown. Other Mattauch-Herzog mass spectrometers have also been flown. The Miranda Laboratories remote particle sensor is a Phase II SBIR.

RELATED ACTIVITIES

There are several ongoing activities at the GSFC which are expected to provide new monitoring hardware and environmental information for the Space Station. The Miranda Laboratories remote particle sensor, as mentioned, is in Phase II of its development. It is a laser light-scattering device. SKW, another scientific research company, is developing another remote particle sensor, using a strobe light and an image analyzer. These activities will hopefully bring needed capabilities into what is currently a technologically weak area in space contamination monitoring.

Another SBIR contract from Goddard is with Science and Engineering Associates, Inc. Its objectives are: 1) to develop a flight experiment to measure the gaseous environment of the Space Shuttle; 2) to measure the return flux of a known gas released into the orbiter environment; and 3) to verify a new computer code for molecular transfer. The development of the flight experiment is expected to produce a mass spectrometer well suited to Space Station contamination monitoring. Furthermore, there is a joint NASA/ESA effort to produce an in-flight contamination experiment. The hardware in this case will be QCMs and effusion cells placed on a variable-length mast deployed from the Shuttle bay. The goal is to measure return flux from known sources, and direct flux from the Shuttle payload bay.

SUMMARY

Work Package 3 is developing a contamination monitoring system whose primary goals are to monitor external contamination levels and to act as a warning system for externally mounted science payloads. We have identified several hardware candidates to compose self-contained monitoring packages. Tentative locations on the APAE and POP have been established for these packages. A number of related analytical and laboratory activities are also being performed to support the CMS design.

N89-15794

Plasma Interactions Monitoring System

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The plasma environment around the space station is expected to be different from that environment which occurs naturally at these altitudes because of the unprecedented size of the space station, its orbital motion, and its high power distribution system. Although there are models which predict the environment around the station, they do not take into account changes in configuration, changes in the natural and induced environments, nor interactions between the different environments.

There will be unique perturbations associated with the space station, which will vary as the space station is being developed. Even after the developed space station has been completed environmental conditions will change as the payloads are changed and as the station systems and materials undergo degradation and modification.

Because the space station will be a point of many varied activities the environment will continually undergo perturbations from effluents resulting from operations of the reboost module, EVA, airlock operations, and vacuum venting. The use of the Mobile Service Center will cause disturbances which cannot, at this time, be predicted. In addition, the operations of attached payloads, (e.g. ASTROMAG) themselves will undoubtedly cause perturbations to the ambient environment. Finally, the natural environment will change as a result of natural perturbations such as solar flares and geomagnetic storms.

To respond to the need to study and understand the space station environment and its variability, a Plasma Interactions Monitoring System (PIMS) shown in Figure 1 has been proposed. The objectives of the PIMS are threefold. First, the PIMS will contain the instrumentation needed to monitor the plasma interactions with the space station and its system (e.g. the power system) to determine the effects of these interactions on the user environment, and on system efficiencies and lifetimes. Second, the data from the PIMS measurements will be used to develop an environmental data base to be used by attached payload developers. This data base will define the "background environment" around the station the resulting perturbations by natural and induced events and activities. Finally, the PIMS will perform those plasma measurements needed to verify the space station environmental specifications (e.g. EMI Control Process Requirements JSC 30326, Plasma Effects Control Process Requirements JSC 30252, External Contamination Control Requirements JSC 30426, etc.).

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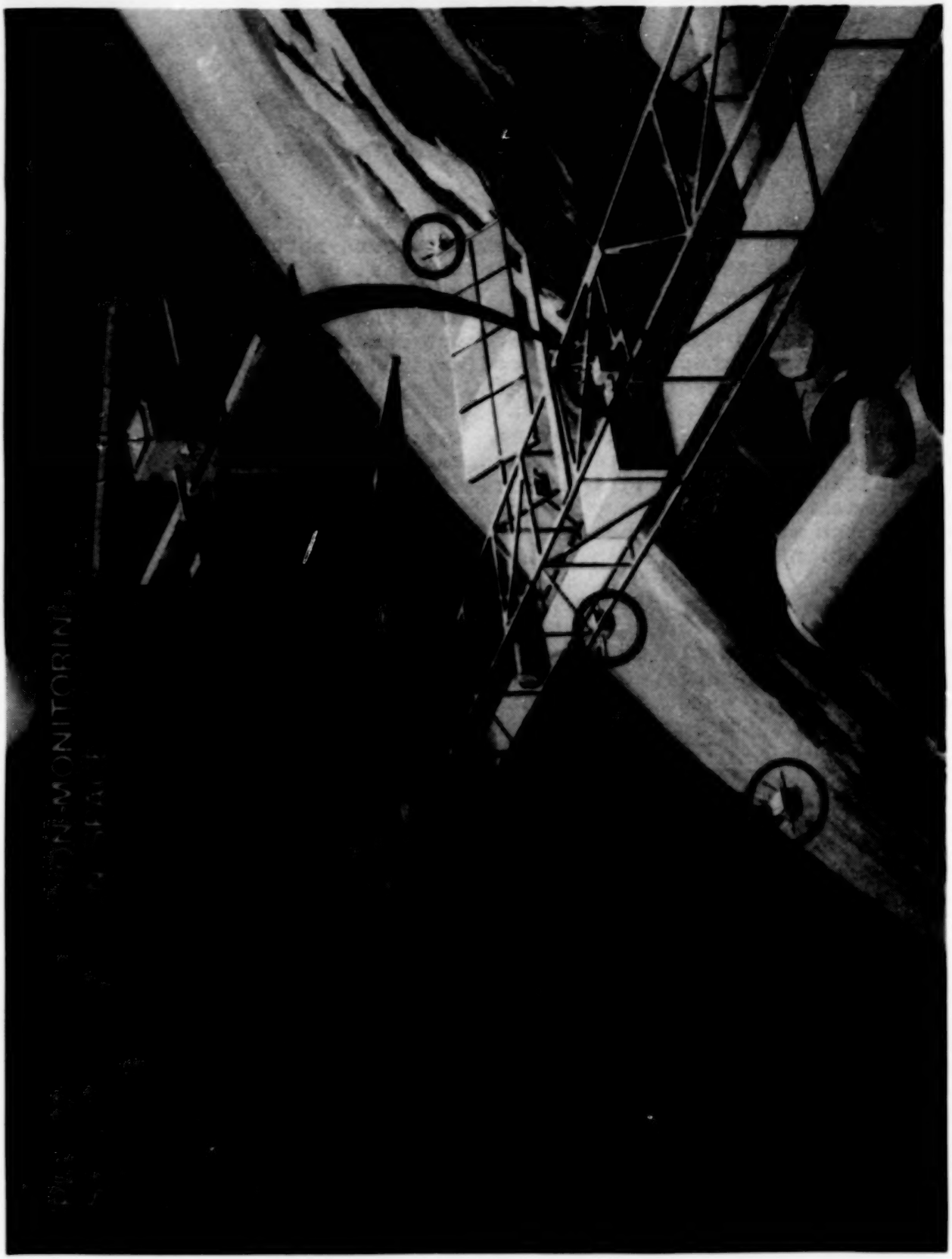

Figure 1. The Plasma Interaction Monitoring System (PIMS).

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In order to carry out these objectives it will be necessary to perform measurements of the plasma and field environment at multiple points around the space station. These measurements will be taken at "critical points" to allow the development of a dynamic space station environmental model.

Early in 1988 a PIMS Study Team was formed to define the environmental measurements required, the instruments needed to perform these measurements, and to specify the required placement of the PIMS units and instruments. The team is comprised of experimentalists, theoreticians, modelers, and data specialists, in the fields of plasma physics and atmospheric science. The membership of the PIMS Study Team and their affiliations are given in Table I.

The PIMS Study Team has spent the past four months defining those particle and field measurements needed to characterize and model the space station environment and environmental extremes. It became evident at the outset of this study that, in order to understand the plasma environment, measurements of neutral densities and species would be required. Hence, a neutral mass spectrometer immediately became a required instrument. The current set of required PIMS instruments is given in Table II.

In addition to the prime instruments shown in Table II it was recently decided to add instruments to measure deposition rates and radiation dosimetry. These data would be carried as "housekeeping" to provide an assessment of prime instrument health and calibration. This "housekeeping" data could also be made available to others interested in deposition rate and radiation environment variability.

Placement of the PIMS units and instruments has been something of a problem because of the uncertainty regarding the accommodation provisions. The Space Station Program has deferred the decision to accommodate small payloads (such as PIMS) at "non standard attach points". Although we feel confident that the space station will eventually provide these accommodation capabilities, our efforts have nevertheless been hampered by the lack of definition of these accommodation provisions. We have been working with NASA space station personnel, and with all of the Work Package centers and contractors to develop the best understanding possible as to how payloads such as PIMS will be accommodated. Also, there is considerable uncertainty about payload accommodations outside the space station "alpha joints" (the gimbal system which rotates the solar panels at right angles to the transverse boom). The PIMS measurements are needed at these locations because they represent the space station "extremities". Also the measurements of fields near the solar panels are needed to detect arcing and other electrical discharges on and near the solar panels.

Table I

PLASMA INTERACTIONS MONITORING SYSTEM

STUDY TEAM MEMBERS

JOSEPH BARFIELD (CHAIRMAN)	SOUTHWEST RESEARCH INSTITUTE
JIM BURCH	SOUTHWEST RESEARCH INSTITUTE
GEORGE CARIGNAN	UNIVERSITY OF MICHIGAN
IRA KATZ	S-CUBED, MAXWELL LAB.
GERRY MURPHY	UNIVERSITY OF IOWA
RAY RANTANEN	SCIENCE AND ENGINEERING ASSOCIATES, INC.
JIM SULLIVAN	MASSACHUSETTS INSTITUTE OF TECHNOLOGY
BILL TAYLOR	TRW INC.
HUNTER WAITE	SOUTHWEST RESEARCH INSTITUTE
ELDEN WHIPPLE	UNIVERSITY OF CALIFORNIA AT SAN DIEGO
DAVID YOUNG	SOUTHWEST RESEARCH INSTITUTE

Table II

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PLASMA INTERACTIONS MONITORING SYSTEM

PRELIMINARY LIST OF CANDIDATE INSTRUMENT CHARACTERISTICS

PARAMETER	RANGE	PARAMETER	RANGE
ION COMPOSITION AND VELOCITY DISTRIBUTION	1 amu ≤ MASS ≤ 128 amu $10^3/CM^3$ ≤ DENSITY ≤ $10^8/CM^3$ V_X, V_Y, V_Z ≤ 8 Km/sec	DC ELECTRIC FIELD	E_X, E_Y, E_Z ≤ 10V/m
		AC ELECTRIC FIELD	10^{-5} V/m ≤ E ≤ 1V/m f ≤ 30 MHz
ELECTRONS	≤ 10 Kev 0° ≤ PITCH ANGLE ≤ 180°	DC MAGNETIC FIELD	B_X, B_Y, B_Z ≤ 1.0G
THERMAL ELECTRONS	$10^4/CM^3$ ≤ DENSITY ≤ $10^8/CM^3$ 0.1ev ≤ T_e ≤ 1.0ev	AC MAGNETIC FIELD	10^{-12} T ≤ B ≤ 10^{-7} T f ≤ 30 KHz
NEUTRAL GAS COMPOSITION AND VELOCITY DISTRIBUTION	1 amu ≤ MASS ≤ 128 amu $10^8/CM^3$ ≤ DENSITY ≤ $10^{14}/CM^3$ V_X, V_Y, V_Z ≤ 8 Km/sec	PLASMA POTENTIAL	≤ 100V

Measurements will be made in the vicinity of attach points since it is here that most attached payloads will reside. PIMS units will also be placed at critical points to measure backflow, scattering and other interactions with reboost thruster firings, airlock operations, and vacuum vent ports.

It is also highly desirable to have a PIMS unit on a standoff outside the primary wake and sheath effects to measure "space weather". These measurements are very important if one hopes to understand and model the induced interactive environment.

As the first phase of the PIMS definition study is nearing completion, the PIMS team is developing an instrument matrix which will show accommodation requirements for each instrument. An example of a partial PIMS matrix is shown in Table III. This matrix will be used in the follow on phase of the PIMS definition study which will address those support subsystems required by the PIMS instruments. The second phase of the PIMS definition study is scheduled to start in the fall of 1988.

During phase II we will define and conceptually design the command and data management subsystem, the electrical power distribution subsystem, the thermal control subsystem, the antenna and boom deployment fixtures. In addition, we plan to intensify our interactions with NASA space station personnel and contractors to penetrate the method of attachment and accommodations for power and data. We also plan to perform an integrated analysis of the PIMS units to determine instrument to instrument interactions. Finally, as design drivers are identified we will initiate trade studies to optimize the PIMS capabilities. These trade studies will primarily address instrument capabilities versus cost. We hope to initiate the PIMS design and development in FY 1990.

Table III

THIRD PIMS TEAM MEETING

PIMS INSTRUMENT MATRIX

INSTRUMENT	DIMENSIONS (cm)	MASS (kg)	POWER (watts)	DATA RATE (kbps)
NEUTRAL GAS COMPOSITION MASS SPECTROMETER (2 SPECTROMETERS)	2X (20 X 20 X 20)	20	30	2
NEUTRAL GAS TOTAL DENSITY GAUGE	10 X 10 X 10	1	1	0 - 0.1
AC/DC ELECTRIC/MAGNETIC FIELDS	20 X 20 X 18	5	5	LOW SPEED: 5 HIGH SPEED: TBD
ELECTRON SPECTROMETER (.01-10 KeV)	15 X 15 X 20	5	5	5
ION MASS SPECTROMETER (0-50 eV)	25 X 25 X 25	8	8	15
ION MASS SPECTROMETER (.01-10 KeV)	25 X 25 X 35	10	10	15
LANGMUIR PROBE	18 X 18 X 3	1	1	1

N89-15795

THE SPACE STATION NEUTRAL GAS ENVIRONMENT AND THE CONCOMITANT REQUIREMENTS FOR MONITORING

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Introduction

At 340 km, for typical conditions, the neutral atmospheric density is several times 10E8/cc and is thus more abundant than the ionized component by several factors of 10. At that altitude, the principal series is atomic oxygen with 10% N2, and 1% He, and trace amounts of O2, H, N, NO, and Ar. The constituent densities are highly variable with local time, latitude, and geophysical indices. The physical interaction with surfaces at orbital velocity leads to large build up of density on forward faces and great depletions in the wakes of objects. Chemical reactions lead to major modifications in constituent densities as in the case of the conversion of most colliding oxygen atoms to oxygen bearing molecules. The neutral environment about an orbiting body is thus a complex product of many variables even without a source of neutral contaminants. The addition of fluxes of gases emanating from the orbiting vehicle, as will be the case for the Space Station, with the associated physical and chemical interactions adds another level of complexity to the character of the environment and mandates a sophisticated measurement capability if the neutral environment is to be quantitatively characterized.

As an economic matter, it will be impractical to monitor, on a continuous basis, the directional neutral fluxes over the 4pi steradians that would be required to fully describe the neutral environment. Several instruments would be required with state-of-the-art velocity and directional determination capability, large dynamic range, high data rate, large power budget, and miscellaneous other costly attributes. An alternative approach is to employ a model of the environment that would be constrained and iterated by a less ambitious set of measurements. One or two sophisticated, directional mass spectrometers supplemented by total density gauges at several locations may provide an adequate input to the model to enable a reasonable characterization of the neutral environment. The requirements for the mass spectrometer and a total density gauge will be developed and a discussion as to the tradeoffs associated with the number of such instruments deployed will be given to help provide the basis for a reasonable assessment of the overall requirement.

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Mass Spectrometer

The mass spectrometer has the advantage of non-specificity and is thus, in principal, capable of detecting all species within its design mass range. Certain practical considerations, however, impose limitations that must be understood and, in some cases, it may be necessary to provide alternative capability in order to achieve the desired measurement. Typical laboratory mass spectrometers have two particularly important limitations: 1) reactive atoms and radicals are modified on instrument surfaces and 2) sticky molecules like water, which is an important contaminant in most manned space flight situations, tend to accumulate on instrument surfaces creating an initial deficit in the measured amount, but subsequently and more importantly imposing a background contribution to the measurement that masks smaller incremental changes. Various techniques are available to mitigate both of these important limitations but their implementation adds complication to an already complex measurement.

Because the source of neutral species can be either ambient or contaminant, the velocity of a measured neutral can vary from virtual zero to the orbital velocity. To characterize the neutral environment through measurement, the velocities should be measured and the trajectory direction should be determined. These requirements pose significant additional complexity to the measurement. Fluxes measured in the direction of the velocity vector are enhanced above ambient by the velocity of the satellite and correspondingly decreased in the wake. The wake measurements can easily be dominated by instrument background contributions if great care is not taken to reduce or resolve this contribution.

Mass range and resolution tend not to be problems in this application. Generally, a mass range from 1-150 is adequate for most measurable contaminants, but extension to higher mass values poses no great difficulties. Unity mass resolution is sufficient for most purposes of this application and is easy to achieve. The instrument would be under control of a microprocessor providing a wide range of measurement programs which, together, permit both survey modes at moderate temporal resolution and single mass modes of very high temporal resolution and all combinations between these limiting cases.

An articulated or portable measuring unit could be capable of observing in all directions of the 4pi space. It would probably be preferable to include two instruments so that simultaneous observations at two view angles would be enabled. In some cases this could permit triangulation, and probably in most cases, the dual observation of a contaminant flux would be a powerful aid in identifying the source and/or scatterers of a measured species. The preliminary requirement will call for two instruments, but this is certainly a debatable point and one can argue for more or less. Total density gauges are reasonably

simple to implement and would enhance the capability for spatial and temporal resolution of contaminant events. An array of 10-20 gauges is recommended. The details of their deployment and location would be determined through a study of the Space Station geometry using the model of the neutral environment.

Specifications for the Mass Spectrometer

1.	Implementation	Two identical instruments (articulated or portable to provide 4pi FOV.)
2.	Mass Range	1-150
3.	Mass Resolution	Unity
4.	Sensitivity	2.5E-3 counts/sec/part/cc source density
5.	Angular Resolution	5 degree solid angle
6.	Velocity Range	0-10 km/sec
7.	Velocity Resolution	0.5 km/sec
8.	Temporal Resolution	.016 sec/mass
9.	Data Rate	1000 bps/instrument (2KBS)
10.	Power	15 Watts/instrument (30 Watts)
11.	Weight	10 kg/instrument (20 kg)

Specification for the Total Density Gauges

1.	Implementation	Array of 16 gauges
2.	Sensitivity	3E-22 amps/part/cc
3.	Angular Resolution	TBD
4.	Temporal Resolution	Variable down to .001 sec
5.	Data Rate	Variable 0-1 KBS for the array
6.	Power	16 Watts for the array
7.	Weight	16 kg

N89-15796

A COMPACT IMAGING SPECTROMETER FOR STUDIES OF SPACE VEHICLE INDUCED ENVIRONMENT EMISSIONS

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Abstract. On the basis of spectral measurements made from the Space Shuttle and on models of the possible Space Station external environment, it appears likely that, even at the planned altitudes of Space Station, photon emissions will be induced. These emissions will occur to some degree throughout the ultraviolet-visible-infrared spectrum. The emissions arise from a combination of processes including gas phase collisions between relatively energetic ambient and surface emitted or re-emitted atoms or molecules, where the surface raises some species to excited energy states. At the present time it is not possible to model these processes or the anticipated intensity levels with any accuracy, as a number of fundamental parameters needed for such calculations are still poorly known or unknown. However, it is possible that certain spectral line and band features will exceed the desired goal that contaminant emissions not exceed the natural zodiacal background. However, in the near infrared and infrared, it appears that this level will be exceeded to a significant degree. Therefore it will be necessary to monitor emission levels in the vicinity of Space Station, both in order to establish the levels and to better model the environment. In this note, we briefly describe a small spectrometer that is suitable for monitoring the spectrum from 1200 Å to $\lesssim$12,000 Å. This instrument uses focal plane array detectors to image this full spectral range simultaneously. The spectral resolution is 4 to 12 Å, depending on the portion of the wavelength range.

Introduction

Information on the nature of induced optical glows and halos near space vehicles is limited at present, and fundamental spectral characteristics have not yet been measured. While the uncertainties are large, preliminary studies (see, for example, Torr 1988; Fraser et al., 1988) indicate that spectral emission levels near Space Station should be monitored on a routine basis. We have developed a small imaging spectrometer which can be readily accommodated for the purpose of measuring induced spectral contamination over a wavelength range extending from the ultraviolet to the near infrared. A schematic illustration of the instrument is shown in Figure 1. The design takes advantage of state-of-the-art technology, and what has been learned in the

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past ten years of developing imaging spectrometers for use in space, to achieve considerable data gathering capability in a compact package that is very undemanding in terms of resource requirements. Two of the units shown in Figure 1 are required to cover the full wavelength range discussed here.

Compact Spectrometer Design

The optical configuration of the instrument is shown in Figure 2. An off-axis parabolic telescope mirror images the field of view onto the entrance slit to the spectrometer. The slit is followed by a concave, aberration-corrected grating which acts as both the dispersion and the focussing element. The spectrum is then imaged on the focal plane detector system which consists of an intensified charge coupled device (CCD) array. As was mentioned above, two such units are required to cover the full wavelength range of 1200 Å to $\lesssim$12,000 Å; one covering the ultraviolet (1200 Å to 4000 Å) and the second covering the visible/near infrared (4000 Å to $\lesssim$12,000 Å). The spectrum from 1200 Å to ~12,000 Å is imaged simultaneously. Therefore there are no temporal ambiguities in correlating one part of the spectrum with another. This capability is important in assessing the features at times when the environment might be changing relatively rapidly (for example; terminator crossings, articulation of payload elements, ventings, etc.).

As the wavelength range of each unit exceeds the effective range of any single photocathode material, the image intensifiers used here are highly customized with one half of the intensifier window coated with one material, and the other half coated with another. Furthermore, the grating is divided into sub-elements. The longer wavelength channel incorporates a matrix of four gratings, each designed for a segment of the wavelength range (4000 to 6000 Å, 6000 to 8000 Å, 8000 to 10,000 Å, and 10,000 to 12,000 Å, respectively). The gratings are individually designed and aligned in such a way that all four produce a flat spectrum on the same image plane. The focal plane is defined by the window of the image intensifier. In the case of the visible/near infrared channel, half of the photocathode is S20, and half is S1. The image plane is illustrated in Figures 3 and 4.

In the case of the ultraviolet channel, the grating is split into two and the photocathode is CsTe on one half (1200 Å to 2000 Å) and bialkali material on the other half (2000 Å to 4000 Å).

The detector is a generation II proximity-focussed image intensifier which is fiber-optically coupled to the surface of a 488 x 380 element CCD. The detector is a continuation of several years of development in this area by our group (see Torr et al., 1986). The CCD is cooled to -30 °C to reduce thermal noise, and the longer wavelength channel has the photocathode cooled to ~0 ^{0}C for the same reason. The CCDs are cooled using thermoelectric coolers and heat pipes are used to remove the heat to a cold plate or passive radiator.

The basic instrument parameters are shown in Table 1 and further details of the design and performance are given elsewhere (Torr et al., 1988).

Sensitivity

In order to be able to assess whether the induced spectral environment exceeds the goal for such contamination, namely, the zodiacal background, the monitoring instrumentation should be capable of measuring down to the levels of the natural background. The zodiacal background varies with position relative to the Sun and also with wavelength. However, levels of 0.1 to 0.2 R/A are typical for much of the visible and near infrared.

The instrument sensitivity for a line source is computed from

$$S = \frac{10^6}{4\pi} \cdot A\Omega \cdot \varepsilon \cdot q_e \text{ (counts/sec/R)}$$

where ε is the combined reflectance of the optics and q_e is the quantum efficiency of the detector photocathode. To evaluate this in the visible, where typical mirror reflectivities are 95% and a grating efficiency of 50% is reasonable; $\varepsilon = 0.45$. An average value for q_e in the visible is ~10%. A is the collecting area per channel (4 cm^2) and Ω, the solid angle, is 4.48×10^{-5} sr, so for a line emission in the visible,

$$S_{line} = 0.57 \text{ counts/sec/R.}$$

For a continuum emission the sensitivity would have to be modified by the number of Angstroms per pixel multiplied by the number of pixels in a slit image; i.e., 2000 Å/488 x 3 = 12 Å.

$$\therefore S_{continuum} = 6.84 \text{ counts/sec/R/A.}$$

From this we can compute the time that would be needed to measure a 0.1 R/A signal to a signal to noise ratio of 5. The time required is 36 seconds.

For the UV, the aperture and slit length is doubled and so the sensitivity increases by a factor of 4. In the near infrared, the S1 photocathode material is substantially less sensitive. To measure to the 1R/A level with a signal to noise ratio of 5, a five minute integration is required.

Summary

An instrument with the properties described above would provide a valuable monitoring device for purposes of evaluating levels of contamination emissions in the vicinity of the Space Station, and to provide data necessary to an understanding of the processes taking place in this environment.

Table 1. Summary of Instrument Parameters

Optical Performance	VIS/IR Unit	UV Unit
wavelength range, Å		
channel 1	9800 - 11,800	2000 - 4000
2	7800 - 9,800	1200 - 2000
3	5800 - 7,800	
4	3800 - 5,800	
dispersion	4 Å/pixel	4 Å/pixel; 2 Å/pixel
resolution (at 3 pixels)	12 Å	12 Å; 6 Å
f# per channel	6.25	3.1
focal length	125 mm	125 mm
slit length	7 mm	14 mm
slit width	0.1 mm	0.1 mm
field of view	3.2° x 0.045°	6.4° x 0.045°
Instrument		
weight	6 kgms	6 kgms
dimensions	30 x 20 x 70 cm^3	30 x 20 x 70 cm^3
power	20 watts	20 watts

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Torr, D.G., Space Station contamination study: assessment of contaminant spectral brightness, in Proceedings of Workshop on Space Station Contamination, ed. M.R. Torr, J.F. Spann, and T.W. Moorehead, NASA Conference Publication, 1988.

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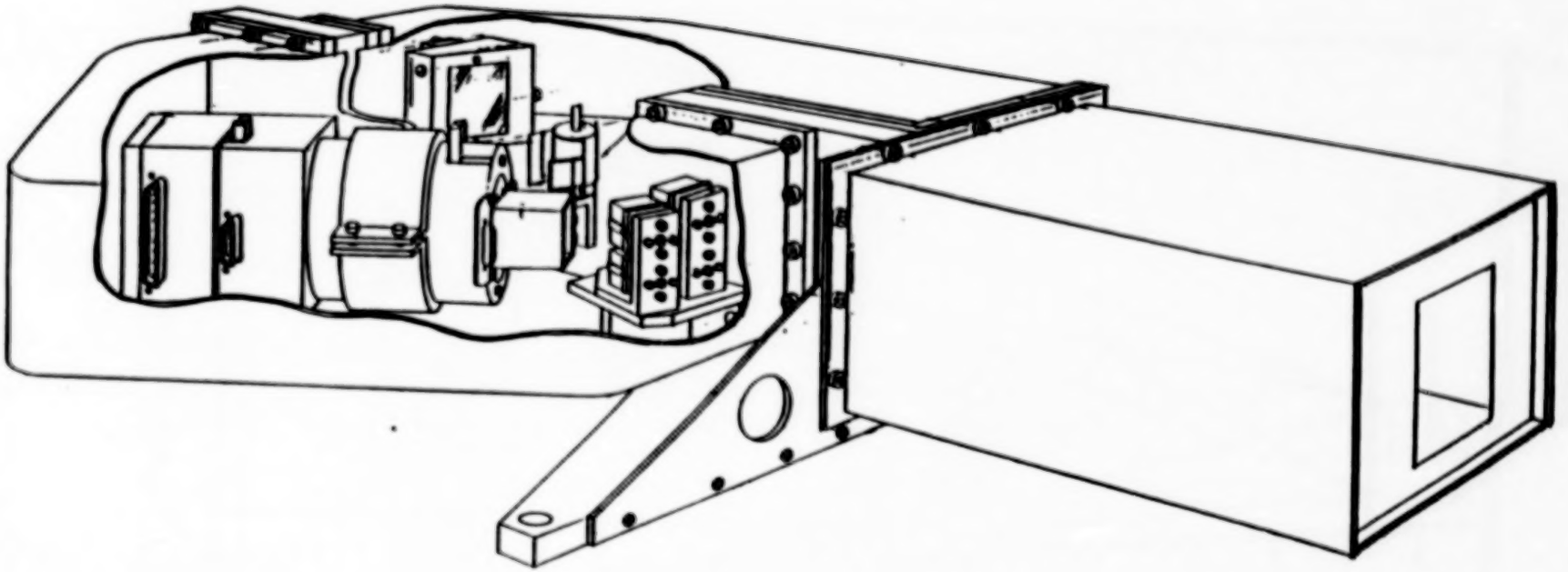

Figure 1. Schematic illustration of one unit of the compact spectrometer.

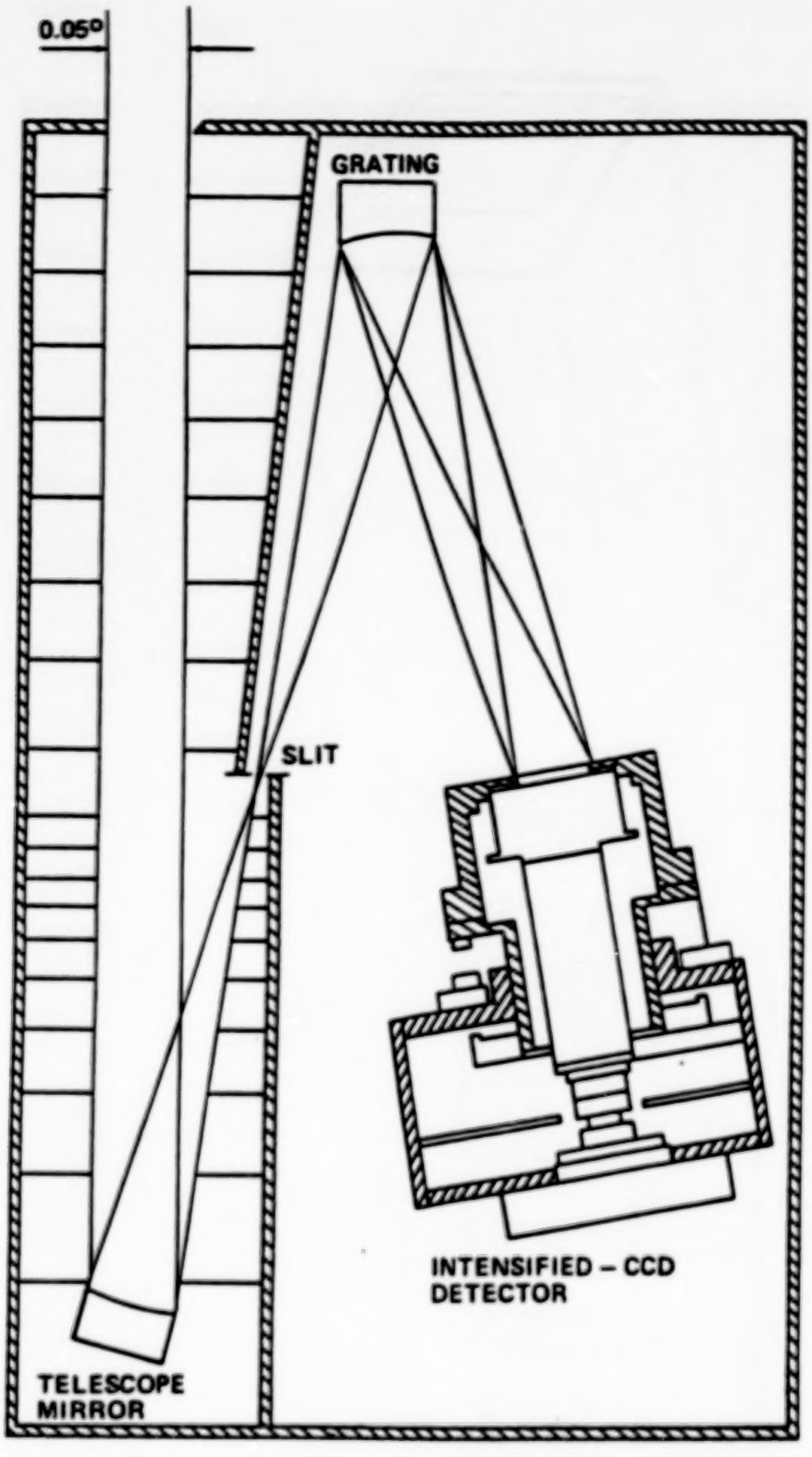

Figure 2. Optical configuration of compact spectrometer, illustrating the split field and the grating matrix.

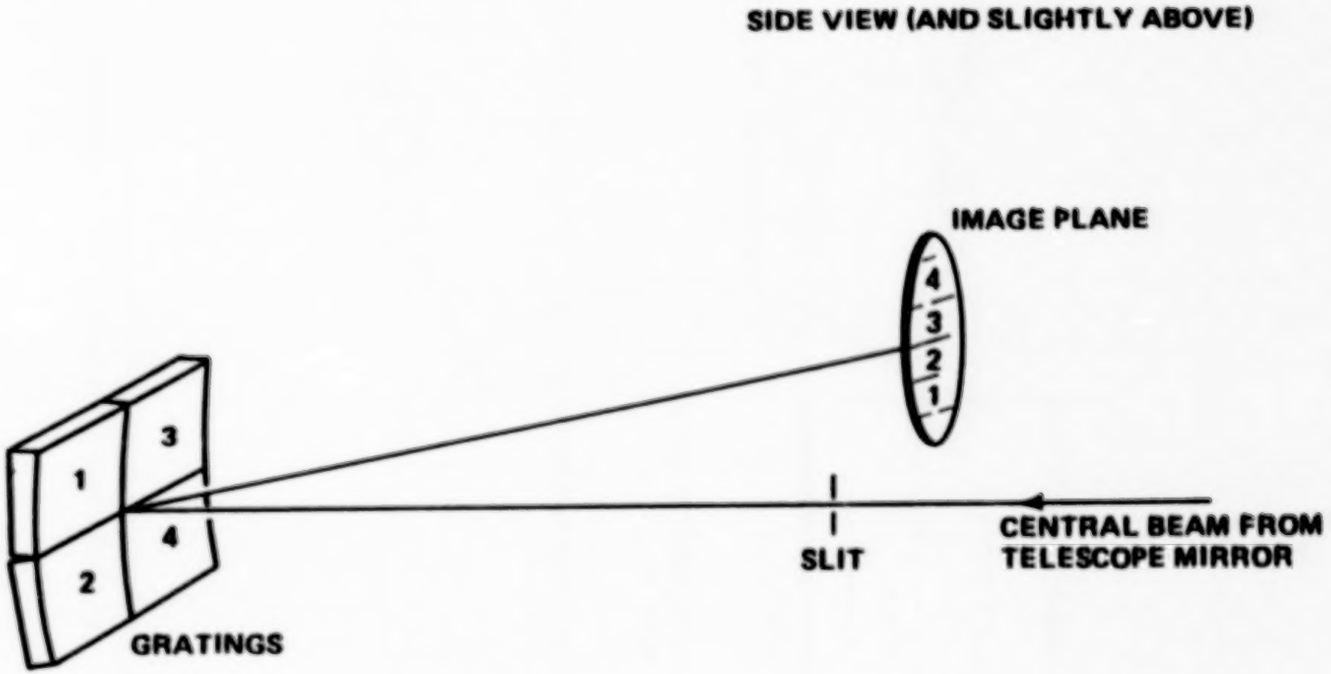

Figure 3. Schematic illustration of the four-grating single focal plane system.

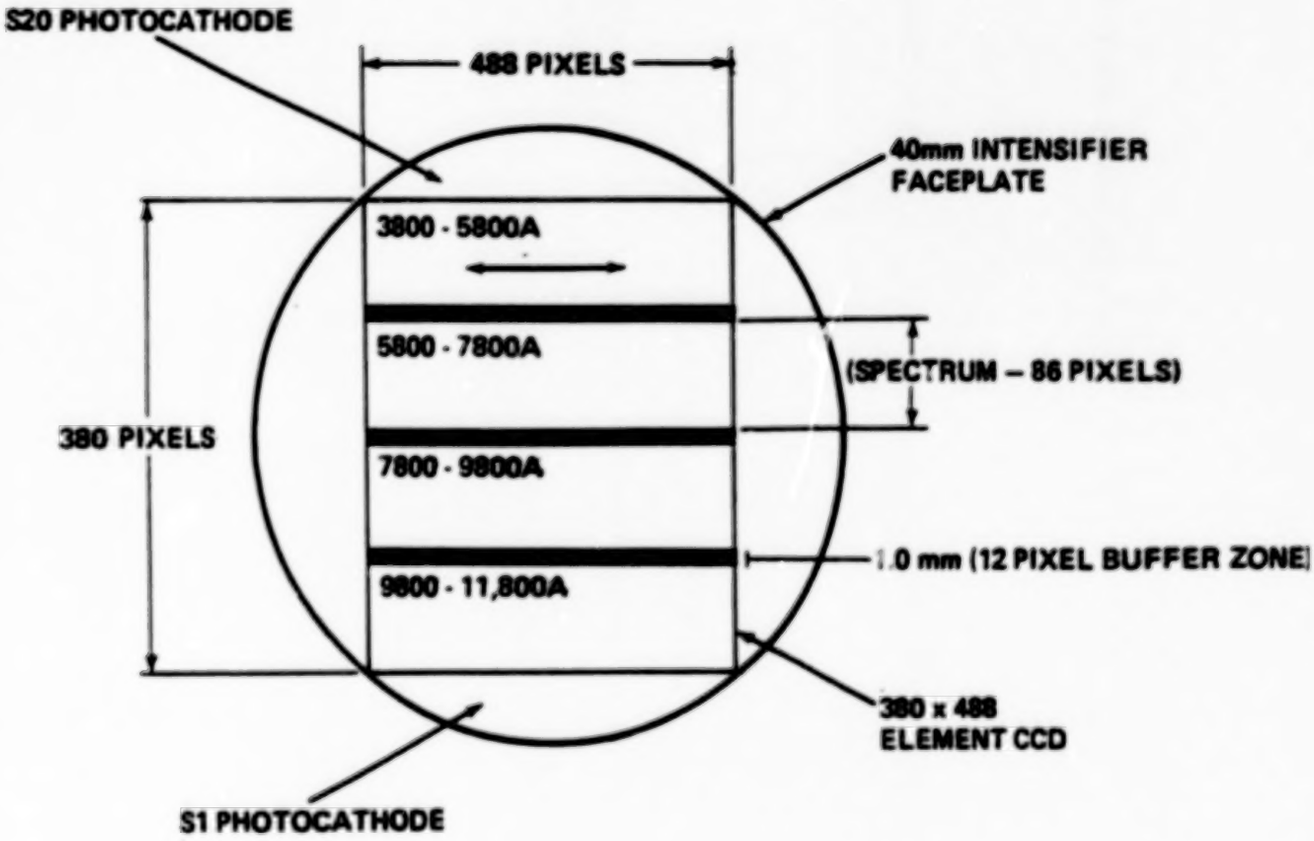

FIGURE 1.2.2 PROJECTION OF SPECTRAL IMAGE ON INTENSIFIED–CCD DETECTOR SYSTEM

Figure 4. Projection of spectral image on intensified-CCD detector system.

N89-15797

INFRARED MONITORING OF THE SPACE STATION ENVIRONMENT

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Introduction

The measurement and monitoring of infrared emission in the environment of the Space Station has a twofold importance - for the study of the phenomena itself and as an aid in planning and interpreting Station based infrared experiments. Spectral measurements of the infrared component of the spacecraft glow will, along with measurements in other spectral regions, provide data necessary to fully understand and model the physical and chemical processes producing these emissions. The monitoring of the intensity of these emissions will provide background limits for Space Station based infrared experiments and permit the determination of optimum instrument placement and pointing direction. Continuous monitoring of temporal changes in the background radiation (glow) will also permit better interpretation of Station-based infrared earth sensing and astronomical observations.

The primary processes producing infrared emissions in the Space Station environment are: 1) Gas phase excitations of Station generated molecules (e.g. CO_2, H_2O, organics...) by collisions with the ambient flux of mainly O and N_2. 2) Molecular excitations and generation of new species by collisions of ambient molecules with Station surfaces. These processes were discussed and modeled by Fraser et al. (1988). They provide a list of resulting species, transition energies, excitation cross sections and relevant time constants. The modeled spectrum of the excited species occurs primarily at wavelengths shorter than 8 μm. Emissions at longer wavelengths may become important during rocket firing or in the presence of dust.

To measure this Station infrared emission spectrum a simple and inexpensive monitoring instrument is desired. It must also have adequate spectral coverage and resolution and a successful spaceflight heritage.

A circularly variable [illegible] (CVF) infrared spectrometer has been developed for studying the [illegible]ed spacecraft glow on the Space Shuttle. This instrument is part of the [illegible]pacecraft Kinetic Infrared Test (SKIRT) with investigators from NASA Goddard Space Flight Center (M. J. Mumma, D. E. Jennings), Air Force Geophysics Laboratory (M. Ahmadjian) and Aerospace Corporation (C. Rice, R. Russell). It is part of an approved Shuttle Hitchhiker program and will be ready for flight in 1990. The spectrometer is being built by Utah State University and Space Systems Engineering and is a modified version of their cryogenic spectrometer which has flown on numerous rocket and space missions (Wyatt and Frodsham, 1977). The spectrometer consists of a CVF covering the 0.7 to 5.5 μm spectral region with a spectral resolution of ~ 2%. The InSb detector is cooled to below 60K using solid N_2 cryogen pumped to space. The instrumental sensitivity (noise equivalent spectral radiance, NESR = 1.5×10^{-13} W/cm^2-sr-cm^{-1}) for a

$2^{\circ}x2^{\circ}$ field-of-view and a 1.52 cm aperture allows the system to reach the zodiacal background limit after 15 min integration. A long wavelength radiometer channel also monitors the 10-12 μm spectral band with a HgCdTe photovoltaic detector. The instrument, solid cryogen dewar and electronics will be mounted in a Get Away Special (GAS) can and will use the Hitchhiker-G Avionics package. An early concept of the instrument is described in Mumma and Jennings (1985).

Instrumentation

The SKIRT infrared spectrometer satisfies the basic requirements for an infrared monitor on the Space Station. It is a simple infrared spectrometer with adequate resolution, space flight heritage and low cost. However, the SKIRT CVF spectrometer will require certain modifications to satisfy the unique Space Station requirements.

In order to permit long term monitoring, as required on the Space Station, the solid N_2 dewar will be replaced by a closed-cycle refrigerator. Closed-cycle helium refrigerators capable of cooling to 65K with long operating lifetime between servicing are available and versions are to fly in space (e.g. the ISAMS experiment on UARS). Due to the large increase in data and possible increase in instrumental flexibility, on board data storage and a data processor will be required. By the time a Space Station monitor will be needed SKIRT will have flown and its data analyzed. These results would be used to optimize the spectral coverage and resolution for a space station version of the instrument. Sensitivity can also be improved by enlarging the field-of-view and increasing the integration time within the constraints imposed by infrared phenomena on the Space Station. A multichannel radiometer covering the 7-15 μm region will replace the SKIRT single channel 10-12 μm radiometer.

A conceptual schematic of the Space Station infrared contamination monitor is shown in Fig. 1. Performance specifications, along with mass, power, data rate and cost are given in Table 1. The instrument will be housed in a truncated GAS cannister or similar container to simplify qualification, transportation and mounting. The instrument can be mounted at any location on the Space Station, but a pointing platform is preferred because this would permit targeting of various areas of the Station. Radiation enters through a door at the top of the cannister. The door will be closed when not in use to protect the optics and detector.

Details of the optical head are shown in Fig. 2. This type of optical head has been built and flown in Air Force space programs for many years by Utah State University and Space Systems Engineering. A baffle at the input rejects stray light. The 1.5 cm primary mirror images the $4^{\circ}x4^{\circ}$ field at a field stop. The primary (pupil) is imaged at an inverse Ritchey-Chretien telescope, which in turn reimages the field at the 0.7-5.5 micron circular variable filter (CVF). The filtered field is then imaged at the InSb detector. A central portion of the collimated beam before the Ritchey-Chretien mirrors is diverted by a flat to a set of radiometer channels, the 7-15 micron part of the spectrum. A series of dichroics divides the spectrum into preselected wavelength bands and each band is focused on a HgCdTe photovoltaic detector.

The optical head will be cooled to 65K with a closed-cycle helium refrigerator. The lifetime between servicing of the refrigerator will be 5 years. A stepping motor mounted on the ambient surface will drive the CVF via a thin-walled stainless-steel shaft (Fig. 1). Electronics and mass data storage units will also be housed within the container.

The mass, power, data rate, and cost listed in Table 1 are inferred from SKIRT and our proposed modifications for Space Station use. Much of the proposed instrument mass (40lbs), power (70W) and cost is driven by the closed-cycle refrigerator. The listed total mass and power requirements can be lowered with future technical advances. The cost (in FY 88 dollars) includes $300K for changing the design to use a mechanical refrigerator instead of a solid N_2 dewar to cool the optics and detectors. The cost does not include transportation on the Shuttle and integration with Shuttle and Space Station, since we expect that the station monitor program would handle all instruments as a package. Also, the cost does not include post-launch operations and data analysis.

Sensitivity

In Table 1 the spectrometer field-of-view and scan time have been increased over those in SKIRT. The resultant sensitivity (corresponding to an NESR ~ 2.7×10^{-14} W/cm^2-sr-cm^{-1}) is sufficient to detect ~10^4 Rayleighs/μm at 3 μm in a single scan (10 sec). Integrating for 100 scans will bring the sensitivity close to the zodiacal limit over the entire 0.7-5.5 μm range.

In Fig. 3 we compare the spectrometer sensitivity (minimum detectable intensity in Rayleighs/μm) to the expected Space Station glow spectrum calculated for a 460 km orbit by Fraser et al. (1988) from a molecular excitation model. The zodiacal background radiation level is shown in the figure. The band centers of several molecular species which contribute to the emission are also shown. Many features will be detected in one scan and the entire spectrum will be measured with longer integration times.

Conclusions

We conclude that a developed CVF infrared spectrometer (SKIRT) and existing technology can be extended to meet the requirements of an infrared contamination monitor on the Space Station. The simplicity of the SKIRT design and its Space Shuttle heritage means that the Space Station infrared monitor can be built for a modest cost with assurance of reaching desired detection limits.

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INFRARED CONTAMINATION MONITOR FOR SPACE STATION

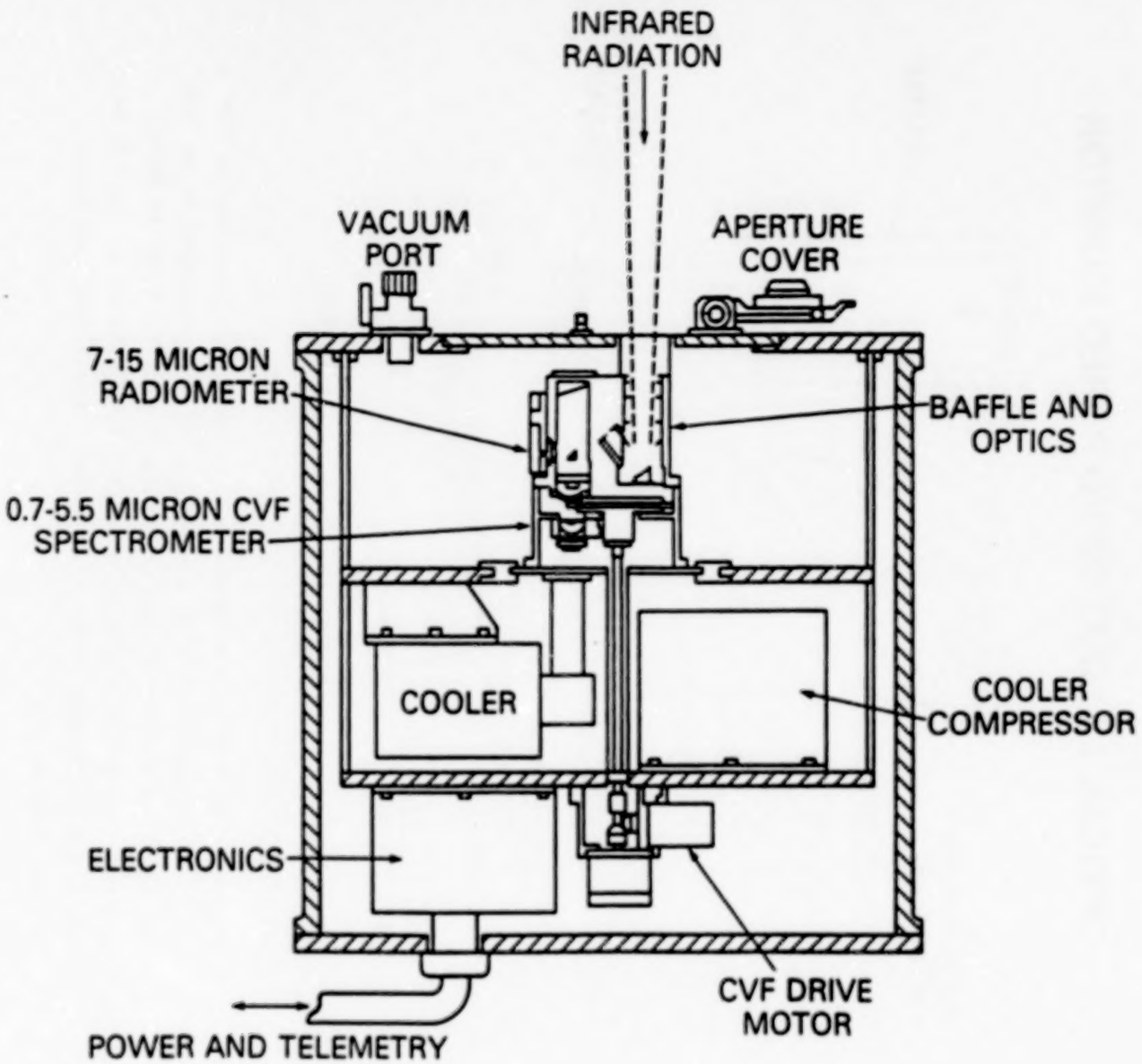

Fig. 1 Conceptual schematic of the Space Station infrared monitor. The optical head will be cooled by a closed-cycle refrigerator. The instrument will be housed in a GAS type container.

OPTICAL LAYOUT OF INFRARED MONITOR

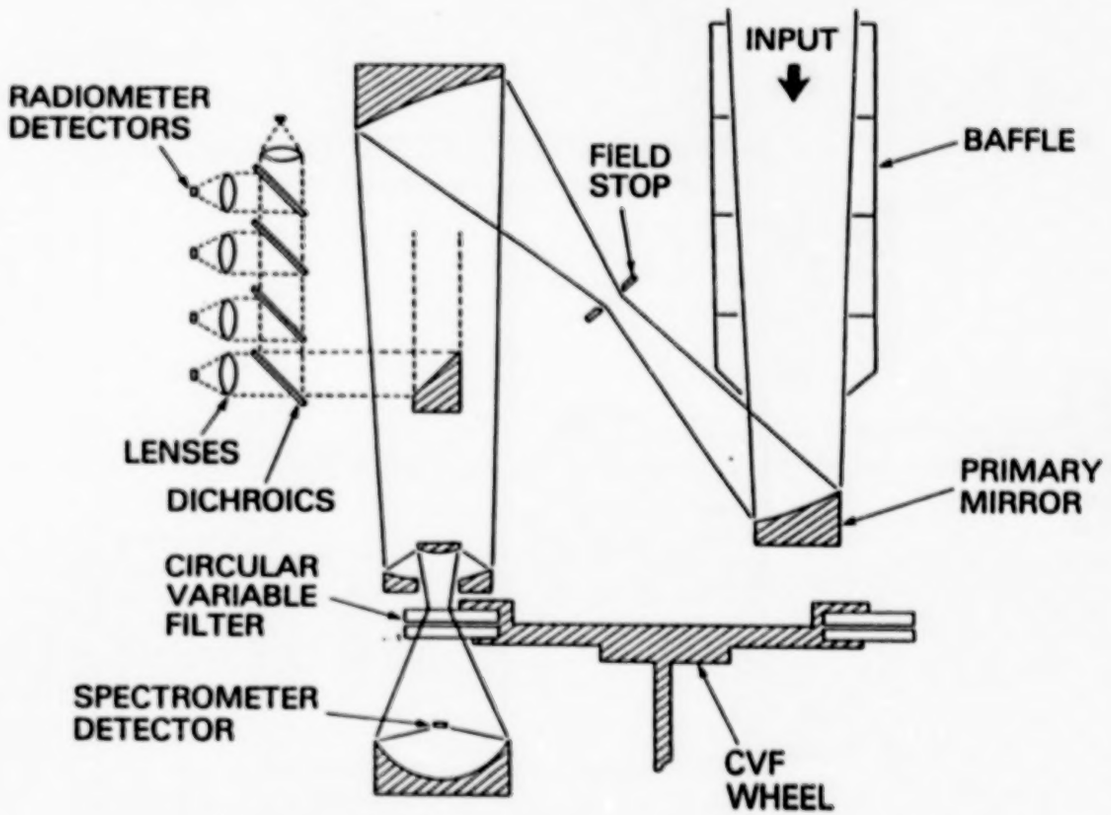

Fig. 2 Schematic of the optical assembly. 0.7-5.5 micron radiation from a 4°x°4 field passes through a rotating CVF and is imaged on an InSb detector. A portion of the radiation is sent to a set of HgCdTe radiometers in the 7-15 micron range. This optical design has been built and flown many times by Utah State University and Space Systems Engineering.

INFRARED MONITOR SENSITIVITIES COMPARED WITH PREDICTED SPACE STATION IRRADIANCE

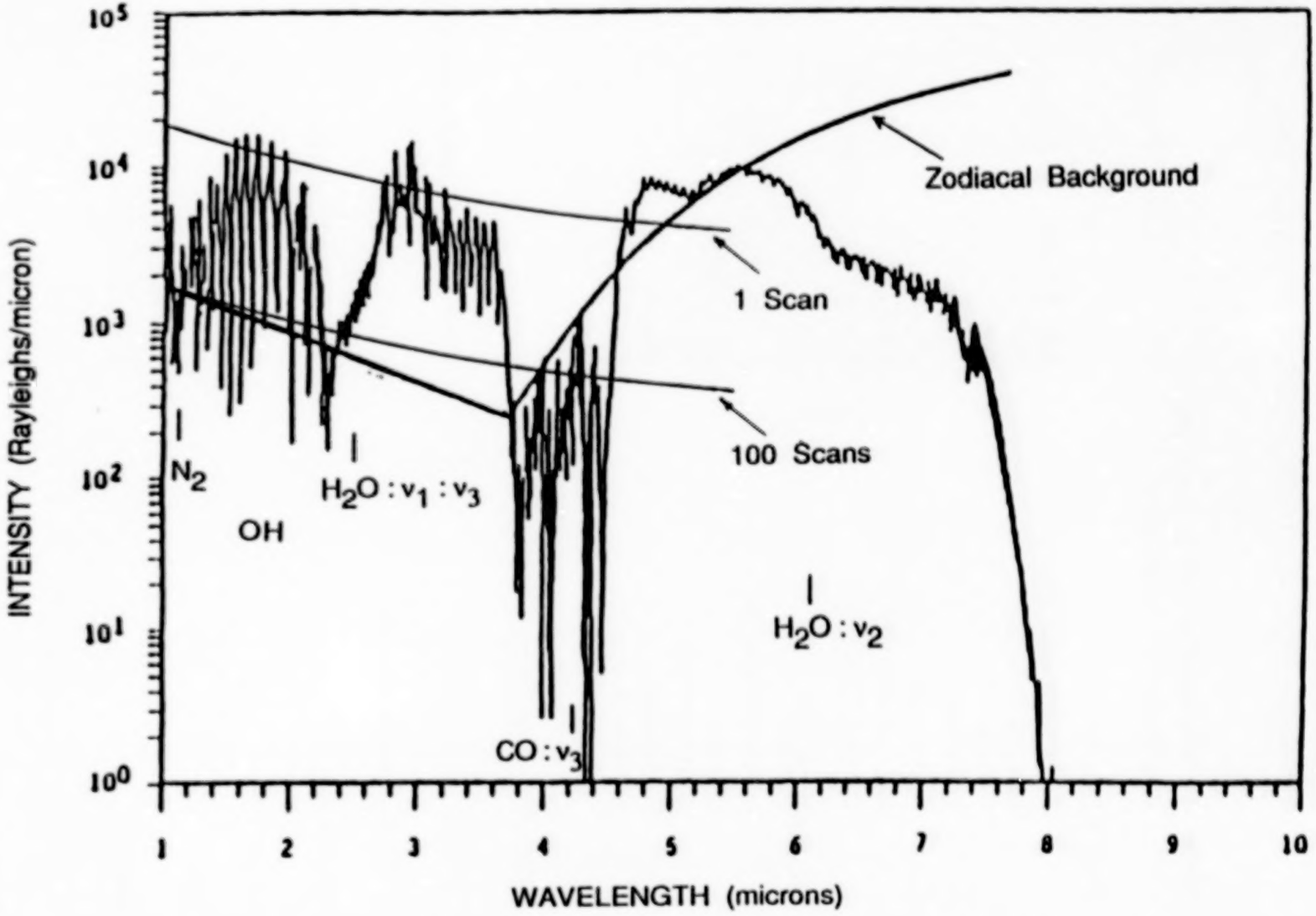

Fig. 3 Comparision of the infrared monitor sensitivities with expected Space Station and zodiacal radiation levels. Adapted from Fig. 2. of Fraser et al. (1988).

Table 1

INFRARED CONTAMINATION MONITOR SPECIFICATIONS

TYPE:	Circular Variable Filter Spectrometer and Single Filter Radiometer
SPECTROMETER:	
wavelength coverage	0.7 - 5.5 μm
spectral resolution	2%
detector	InSb
scan time	10 sec
field-of-view	$4^o x 4^o$
aperture diameter	1.5 cm
sensitivity (NESR)	2.7×10^{-14} W/cm^2 sr cm^{-1}
RADIOMETER:	
spectral bandwidth	7 - 15 μm (multichannel)
detector	HgCdTe (PV)
integration time	0.5 sec
field-of-view	$4^o x 4^o$
aperture diameter	0.6 cm
sensitivity (NER)	2×10^{-9} W/cm^2 sr
OPERATING TEMPERATURE:	65 K
COOLER:	Closed-cycle Helium Refrigerator
LIFETIME (before service):	5 years
CONTAINER:	GAS cannister or similar
LOCATION:	Pointing Platform
SIZE:	20 in dia x 20 in high
MASS:	275 lbs
POWER:	160 W
DATA RATE:	40 kbs^{-1} (on-board storage)
COST:	850 K

N89-15798

REQUIREMENTS FOR PARTICULATE MONITORING SYSTEM FOR SPACE STATION

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Abstract. We recommend that a stereo camera system should be utilized as a diagnostic for the particulate environment surrounding the Space Station. This system should have sufficient sensitivity to identify contaminated periods, to isolate the effects of sources and activities and to determine optical clearing times. A reasonable compromise between sensitivity and other operational constraints is recommended. Sensitivity comparable to the film camera systems should suffice, but long periods of unattended operation and remotely controlled exposure sequences are essential requirements.

Introduction

Particulates surrounding space structures have been recognized to have a potentially serious impact on the ability to perform optical observations from space based platforms. Their effects will be manifested as scattered solar or reflected local emissions in the ultraviolet through near IR spectral regions. At wavelengths beyond 3 μm particle reflected earthshine and thermal self emission will dominate its signature (Rawlins and Green, 1987). In addition to providing broad spectral interference, the particulate emission will be spatially/temporally varying posing serious constraints on radiometric (non-imaging) systems. Particulates may cross a field of view in less than a second and even within this time non-spherical particles have been observed to have rapidly varying emission levels as various aspects of its surface are presented to the observation system.

The recommended guidelines in JSC 30426 (1986) call for the environment to be constrained to having less than one particle per orbit detectable in a 1.5×10^{-5} steradian field of view. For 90% of the time only particles with diameters less than 5 μm are permitted to be present within 10 km of the station within the volumes designed as optical observations vieving regions.

The diversity of orbital observations of particulates have been revieved previously (Green, 1988). The particulates arise from ground processing, crev activities on-orbit (such as EVAs, dumps) and orbital interactions (such as erosion, micrometeorite impacts).

The previous observations have demonstrated that solar illumination angle is the key parameter in the visible. Observations of the Shuttle environment have been limited to particulates larger than 40 μm diameter at distances of less than 100m from the Shuttle. The occurance of these particulates was very variable ranging from nearly no up to 50 particles detectable in a 10^{-5} sr

field of view. Scaling to the densities expected for sizes down to 5 μm will require modeling. The IECM data indicates that smaller particles are more numerous and that observed velocities (obtained by a careful analysis of stereo film data [Miller, 1983; Clifton and Owens, 1988; Clifton and Benson, 1988; Miller and Clifton, 1988]) ranged from 0.3 to 3 m/s. Models of the particle trajectory indicate that both the initial ejection velocity and drag contribute to the observed trajectory.

The film camera systems have proven that stereoscopic operation can provide accurate range and velocity determinations. They also provided essential long term trend data. Film camera shutter exposure sequences (Miller, 1983; Green et al., 1987) limit observations to processes on the 0.3 to 10 second or two minute time scales. Only particulates larger than 40 μm could be detected during the sunlit portion of the orbit. Sensitivity thresholds could be substantially altered by varying film speed, exposure duration, and post processing/image enhancement techniques. Although film provided a high information density archival storage medium, response correction was a tedious procedure and data analysis occurred long after the mission. Real time warnings or correlations were not possible.

A Recommended Particulate Monitor for Space Station

A diagnostic monitor for Station should attempt to overcome the limitations of the camera systems described above yet retain adequate sensitivity. Sensitivity sufficient to monitor the environment to the levels recommended in the guidelines does not appear to be achievable except by large observatory facilities such as Space Telescope, IRT or SIRTF (whose requirements contributed to guideline establishment). Moreover it is very desirable for the particulate monitor to be small, continuously operating and require low maintenance. A reasonable compromise between sensitivity and the other operational constraints is to recommend a system with sensitivity comparable to the film camera systems which can operate unattended for long periods of time and which is remotely controllable to permit exposure sequencing to be varied so that the range of orbital effects can be more easily interrogated over the entire orbital cycle. A stereoscopic system will again permit position and velocity information to be deconvolved to determine source locations and times. Both passive and active systems should be considered. Mounting on a trackable platform will permit large spatial volumes to be probed for locally severe environments.

This particulate monitoring system easily lends itself to being part of a larger total environment monitoring system. Although its size would be dictated by the optical baffles required for out of field light rejection, the detection elements can be made lightweight and should have low power requirements.

We recommend that the system should have sufficient sensitivity to identify contaminated periods, to isolate the effects of sources and activities and to determine clearing times. A low maintenance camera system meeting these specifications will prove to be a useful diagnostic for guiding observational measurement periods and identify orbital sources, trends and time scales.

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N89-15799

SPACE STATION SURFACE DEPOSITION MONITORING

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Abstract. Quartz crystal microbalance sensors are recommended to verify and monitor surface deposition on the early transverse boom as well as the later dual-keel Space Station configurations. Performance and placement of these sensors are discussed and compared to imposed maximum mass deposition rate requirements at the science instrument and critical power locations. Additional measurements are suggested to gain further knowledge on properties of the deposited material.

Introduction

Molecular contamination includes gases that may be adsorbed or absorbed on a surface. Film-like deposits in the liquid and solid phases are also considered molecular contamination.

The world's first space station, Skylab, included quartz crystal microbalances (QCMs) and optical witness samples to monitor contamination and its effects. Of concern to experimenters was both induced contamination and contamination from revisits by manned spacecraft. Similar concerns exist today for Space Station. Since Skylab, QCMs have been the instruments of choice for reliable, sensitive, and economical molecular mass deposition measurements both in vacuum chambers and space flight applications. A popular version utilizes thermoelectric Peltier devices coupled to the quartz crystal. In this manner, the so-called temperature-controlled quartz crystal microbalance (TQCM) can be operated over the temperature range of approximately 80°C to -60°C when the heat sink temperature is 20°C (see Figures 1 and 2).

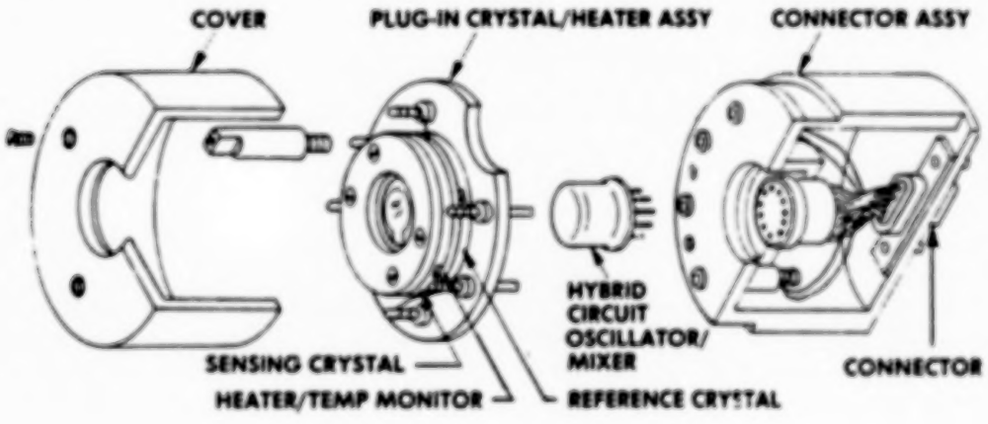

Fig. 1. Exploded View of Quartz Crystal Microbalance Sensor, QCM Research , Laguna Beach, CA

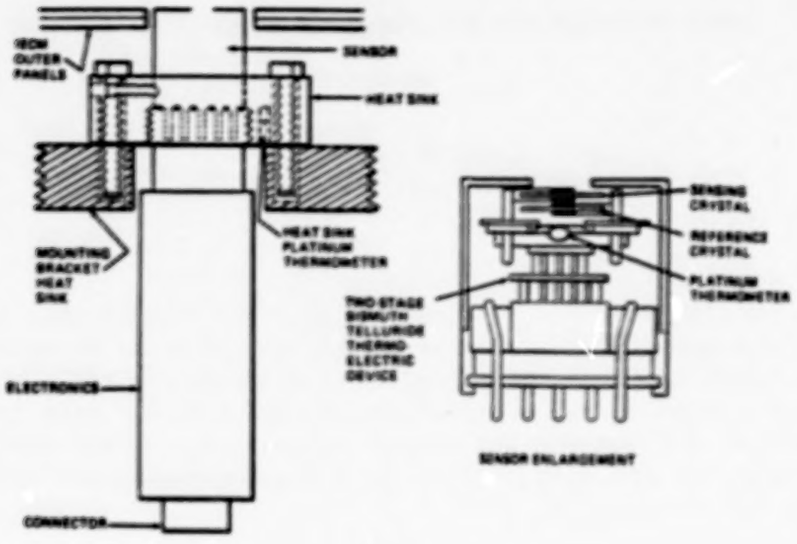

Fig. 2. Schematic of Temperature-Controlled Quartz Crystal Microbalance by Faraday Laboratories Inc., LaJolla, CA. This type was used on the Shuttle Induced Environmental Contamination Monitor (IECM).

Optical witness samples, where there is an opportunity for retrieval, provide an important measurement of deposition effects (this technique is used extensively during ground operations). Active monitoring of optical effects has also been accomplished and can offer real time assessment of the spectral effects of contamination depositions.

It is anticipated that the QCM will still be the instrument of choice for monitoring mass deposition in the Space Station era. Contamination level requirements must be verified, and ongoing monitoring capability must be provided to the extent that events producing undesirable levels can be abated or modified and sensitive instruments can be protected. QCM placement, type, and quantity of sensors will influence the ability to accomplish these tasks.

Requirements

The Space Station External Contamination Control Requirements Document (JSC 30426) states: "....."

4.5.1 Quiescent Periods

4.5.1.4 Molecular Deposition

The flux of molecules emanating from the core Space Station must be limited such that:

4.5.1.4A The mass deposition rate of two 300°K surfaces both located at the PMP with one perpendicular to the +Z axis and the other whose surface normal lies in the horizontal plane and at critical power locations with an acceptance angle of 2π steradian shall be no more than 1×10^{-14} g/cm^2 sec (daily average).

4.5.1.4B The mass deposition rate on a 300°K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 1×10^{-16} g/cm^2 (daily average).

4.5.1.4C The mass deposition rate of a 5°K surface located at the

PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 2 x 10^{-13} g/cm^2 sec (daily average) excluding condensation of atmospheric constituents.

4.5.2 Nonquiescent Periods

4.5.2.1 Molecular Deposition

Total deposition on sensitive surfaces such as solar arrays or either the astronomy or Earth resources observation regions shall not exceed 4 x 10^{-7} g/cm^2 yr.

Even though mass deposition requirements for quiescent periods (operational periods) are stated on a daily averaged 1-sec time basis, the real concern is the net deposition over longer periods of time (weeks to months). The basic detectivity of a TQCM operating at 15 MHz is about 1.6 x 10^{-9} g cm^{-2}. Rates of 1 x 10^{-14} g cm^{-2} s^{-1} (on 300 K, 2π steradian surface) would require a minimum of 44 hours to deposit 1.6 x 10^{-9} g cm^{-2}, and 1 year for approximately 3 x 10^{-7} g cm^{-2}. The latter value could be equivalent to a few monolayers and could possibly cause significant vacuum ultraviolet absorption.

A rate of 1 x 10^{-16} g cm^{-2} s^{-1} on a 300 K surface with an acceptance angle of 0.1 steradian would require 6 months to reach detectable limits; however, if the source can be assumed, or determined, to be isotropic over 2π steradians then a sensible detection could be attained in about 70 hours using detectors with hemispheric acceptance angles.

A more practical acceptance angle for a TQCM measurement would be 1π steradian, doubling the above sensible detection times or integration periods. Due to measurement noise and drift, another factor of 3 should be considered to establish detection and trends at these deposition rates. Thus, about 11 days would be required to establish rates of 1 x 10^{-14} g cm^{-2} s^{-1} 2π steradian and 18 days for rates of 1 x 10^{-16} g cm^{-2} s^{-1} 0.1 steradian on a 300 K surface with a 1π steradian acceptance angle.

To provide a 5 K monitor surface, in order to verify induced contaminant (excluding atmospheric constituents) mass deposition rates on cryogenic surfaces, may be prohibitively expensive. However, a radiatively cooled QCM detector could be designed that, with proper thermal shielding and efficient radiators, could provide surface temperatures down to approximately 130 K, sufficiently low to condense infrared absorbing material of interest. Radiative cooling to these low temperatures would, however, generally not allow orientation of the QCM surface perpendicular to the Z axis.

The location and orientation of the 300 K surfaces are not clearly delineated in JSC 30426. For instance, no X or Y directions are specified for the prime measurement point (PMP) surface whose normal lies in the horizontal plane, or for the surface at the critical power locations. Also, it is not trivial to distinguish the core Space Station molecular flux deposition for other sources such as science instruments. Since these instruments would by and large be mounted at the PMP, molecular flux (direct and return) from such instrumentation could be relatively high due to proximity.

Recommended Measurements

In order that sufficient information be available to determine the quantity of molecular deposition at the PMP and to possibly identify sources, it is recommended that a TQCM package consisting of six TQCMs, one viewing in each direction (±X, ±Y, ±Z), be mounted on the space and earth side on each of the 4 corners. Each sensor would view approximately 1π steradian and nominally operate at 300 K. Also, two additional TQCMs with 0.1 steradian acceptance angles should be mounted on the upper and lower booms with surface

perpendicular to the Z axis and controlled at 300 K. The corner-mounted packages should be positioned such that the sensor views along the boom, i.e., science instrument area sees as many of these instruments as possible. In other words its boom area view should not be obstructed by a near-by instrument. The narrow field TQCMs should be mounted about one-fourth of the total length of the boom from each end and sufficiently above the boom to exclude direct viewing of Station components or instruments.

Two TQCMs with 1π steradian acceptance angle should be located at each of the critical power locations, one whose surface is parallel with the collector surface and the other viewing along the Y axis toward the core Station.

QCMs are currently available with the capability of operating at 5 K. However, it is recommended that this measurement await the installation of a cryogenic instrument located at the PMP. Otherwise, this requirement has little or no basis and would require expensive plumbing. As mentioned above, a radiatively cooled QCM would partially fulfill this measurement requirement.

JSC 30426 does not address the external contamination control requirements for the early configuration transverse boom Station. For instance, the PMP is not defined, but it is assumed that these points are located on the Earth and space sides (with surfaces perpendicular to the Z axis) and are between the module area and the rotation joint for the solar panels. It is also assumed that the deposition rate requirements at the PMP are the same as for the dual-keel Station.

System Design and Operation

The recommended TQCM's require nominal temperature control of the collection surface (crystal) at 300 K. To minimize power requirements the TQCM sensor packaging should be deisgned to provide heat sink temperatures of about 300 K.

Three channels of data are required for each sensor:

(1) frequency between collection and reference crystals - 16 bit s^{-1} maximum, 12 bit s^{-1} nominal, (2) sensor temperature - 8 bits resolution, (3) heat sink temperature - 8 bits resolution.

Sensor crystal heat frequency and temperatures would only be queried infrequently at, say intervals of tens of minutes to obtain sufficient deposition information. Nonquiescent periods, during Space Shuttle visits for example, would require greater sampling frequency (on the order of minutes) to resolve deposition from various activities (proximity operation, docked periods, astronaut EVA's, etc.). Heat sink temperature could be obtained by a single measurement on each of the packages of 6 TQCM's.

Table 1 gives additional pertinent information on TQCM's.

It is recommended then, for similarity and continuity between the early and later Station configurations, that the same package of six TQCMs discussed above be placed on the +Z and -Z sides of the boom about half-way to the rotation joint on the +Y and -Y axes (i.e., a total of four packages). At least one 0.1 steradian TQCM should be placed near each of these locations. All of the above would be nominally controlled at 300 K. Measurements for the critical power locations would be the same as for the dual-keel Station above.

Table 1. Typical TQCM Specifications Sensor.

Sensor:	
Mass Sensitivity	1.6×10^{-9} g cm^{-2} Hz^{-1} (15 MHz crystal)
Temp. range	80° to 60°C (20°C Heat Sink)
Sensor Power	0.15 watts
Peltier Power	0 - 7 watts
Dimensions	3.2 cm diam. x 7.5 cm long
Weight	120g
Controller (For approx. 6 sensors):	
Dimensions	15 x 16 x 16 cm
Weight	3 kg
Rough-order-of-magnitude cost:	
Contoller, 6 sensors - $150K	

Additional Measurements

Two additional measurements are proposed to gain more knowledge of the nature of the deposited mass and the effects of these deposits on optical properties.

The first measurement requires a TQCM mounted adjacent to a neutral mass spectrometer and the capability to mechanically flip the TQCM 180° so that its collection surface is positioned directly over the entrance aperture of spectrometer. Heating the TQCM would allow analysis of collected mass and possible insight into subsequent surface chemistry. TQCM heating rates could be controlled to accommodate the mass spectrometer sweep rates. When gases are no longer evolving, the TQCM is repositioned in the collection mode and commanded to the desired collection temperature.

Prior to installation of extremely sensitive ultraviolet-vacuum ultraviolet (uv-vuv) instruments on the Station it would be desirable to measure the optical effects of deposition directly and inexpensively. A prototype instrument has been developed by Acton Research Corporation, Acton, Massachusetts, under a Small Business Innovative Research contract and technically monitored by MSFC that provides the capability to measure specular transmittance and reflectance at 10 discrete wavelengths over the 121.6 to 210.0 nm region. Up to three samples are mounted in a carousel and exposed to the environment. Optical measurements can be accomplished quickly on any sample at any selected wavelength, sequenced through all the samples at each of the 10 wavelengths, or in a user preprogrammed mode.

These two additional measurements would provide complementary information to that provided by the QCM. We would then have mass, mass spectra, and optical effects as a function of time.

SECTION 2: CONTAMINATION CONTROL REQUIREMENTS

Introduction

This section contains the material from that portion of the workshop that addressed the Space Station External Contamination Control Requirements Document: JSC 30426 (November, 1986). The first paper in this section reviews the various suggested modifications to JSC 30426. This is followed by a summary of these suggestions and the disposition recommended by the working group. Also included in this section is a study of the allowable build up of neutral gases near high voltage sources such as the solar arrays. This study was in two parts: first, R. Rantanen has modeled the predicted build up near the solar arrays for various conditions (see section 5 of the paper by R. Rantanen). Secondly, in a separate paper, N. Singh has computed the levels at which plasma arcing and discharges could be expected to take place.

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N89-15800

CONTAMINATION CONTROL REQUIREMENTS DOCUMENT JSC 30426 RECOMMENDED UPDATES

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Abstract. Contamination control requirements for the Space Station have been evolving over the last few years. Workshops, comments by experimenters and continuing analysis have resulted in recommending changes to the November 19, 1986 version of Space Station External Contamination Control Requirements, JSC 30426. These are summarized and presented herein, so that the requirements can be revised as soon as possible, to minimize costly design impacts on the Space Station.

1.0 INTRODUCTION

The changes recommended to JSC 30426, presented here, are a result of the Jan 28-30, 1987 "Space Station Payload Contamination Compatibility Workshop" held in Denver and subsequent workshops and analyses. The majority of these recommended changes were proposed by payload personnel and the others by members of the contamination control community.

2.0 WORKSHOP RECOMMENDATIONS

The Workshop held in Denver, Jan 28-30, 1987 addressed the current (Nov 19, 1986) Space Station Contamination Control Requirements and changes recommended by the payload/ contamination community. Table I lists the Jan 1987 workshop participants.

TABLE I. LIST OF WORKSHOP PARTICIPANTS.

Jack Barengoltz	-	JPL
James Carney	-	MATSCO/JSC
Nancy Carosso	-	GSFC
Steve Chinn	-	SEA
James Cramer	-	SEA
Alice Dorries	-	MSFC
Gabriel Epstein	-	GSFC
Ray Gause	-	MSFC
Tim Gordon	-	SEA
Patricia Hanson	-	JPL
John Hughes-Blanks	-	SEA
Don Jennings	-	GSFC
Charlie Jones	-	MSFC
Lubert Leger	-	JSC
Carl Maag	-	JPL
Dave McKay	-	JSC

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TABLE I. LIST OF WORKSHOP PARTICIPANTS - Cont.

Gerry Murphy	-	University of Iowa, Iowa City, IO
Gary Musgrave	-	MATSCO/HQS
Sherman Poultney	-	Perkin-Elmer
Ray Rantanen	-	SEA
Reese Reumont	-	JSC
Jeffrey Scargle	-	ARC
Russ Seebaugh	-	SEA
Mark Sistilli	-	SAIC/Washington, DC
Gerald Sharp	-	Univ. Research Foundation, Greenbelt, Maryland
Srini Srinivasan	-	MATSCO/JSC
Doug Torr	-	Univ. of Alabama, Huntsville, Alabama
Marsha Torr	-	MSFC
June Tveekrem	-	GSFC
Fred Witteborn	-	ARC

2.1 RECOMMENDED CHANGES TO JSC-30426

The workshop participants recommended the following changes to the Nov. 19, 1986 version of the JSC-34026 document. These changes pertain to Section 4.0 of that document.

a. Paragraph 4.5.1.1

Insert word "Continuum" before each "background" in the paragraph. Add sentence "Line and band emitting species will have column densities satisfying 4.5.1.2.1.", at the end of the paragraph.

b. Paragraph 4.5.1.1

The requirement stated here should include contributions from particles <5 microns.

c. Paragraph 4.5.1.2.2

The allowable limits in this paragraph should be adjusted to be compatible with Table 4-1, which is the criteria payload personnel will accept.

Old: 1×10^{13} molecules/cm^2 each for O_2, N_2, H_2 noble gases, and for all other UV and non-IR active molecules combined (total not to exceed 5×10^{13} molecule/cm^2)."

Replace 1×10^{13} and 5×10^{13} to read:

New: 2×10^{11} molecules/cm^2 each for O_2, N_2, H_2, for noble gases, and for all other UV and non-IR active molecules combined (total not to exceed 1×10^{12} molecules/cm^2)

d. Paragraph 4.5.1.3.1

Old: Control of particles less than 5 microns in size shall meet TBD requirements

New: Control of particles less than 5 microns in diameter shall not contibute more noise than the zodiacal background, time-averaged over an orbit.

e. Paragraph 4.5.1.3.2

Old: TBD

New: 4.5.1.3.2A - The particle deposition on surfaces with an acceptance angle of 2π sr shall not exceed 0.5 percent obscuration. 4.5.1.3.2B - The change in BDRF due to particle deposition on surfaces with an acceptance angle of 0.1 sr shall not exceed 50 percent (clean versus contaminated).

f. Paragraph 4.5.2.2

Requirements in 4.5.1.3.2 shall apply during both quiescent and non-quiescent periods.

g. Table 4-2

Add "continuum" after "infrared" in the title, and change wavelength ranges as follows:

Old:	(micrometers)
	1
	5
	10
	≤30
	>30
	300

New:	(micrometers)
	1 - 3
	3 - 7
	7 - 15
	15 - 30
	30 - 200
	200 - 500

It is further recommended the final level of 1×10^{12} molecules/cm^2 be verified or updated by Dr. Doug Torr and presented at the next CCWG.

NOTE:The changes to C in paragraph 4.5.1.2.2 above were based on preliminary estimates by Dr. D. Torr. Subsequent to this workshop, Dr. Torr has developed better estimates of molecular densities that meet or exceed zodiacal brightness levels. These new estimates should be collected, reviewed, and used in place of the above recommendations.

3.0 ADDITIONAL RECOMMENDATIONS

These recommendations are a result of workshops and analysis during 1987.

3.1 MOLECULAR COLUMN DENSITIES

The allowable molecular column densities in paragraph 4.5.1.2 of JSC 30426 do not correspond to the zodiacal light levels that are stated in paragraph 4.5.1.1 and tables 4.1 and 4.2. Reconcilliation should be accomplished by requesting Dr. D. Torr, UAH, to update these values based on the synthetic molecular spectra work he has accomplished during 1987.

3.2 EARTH POINTING BRIGHTNESS LEVELS

The location of experiment vents can be optimized to reduce the impact to experiment lines-of-sight. In order to do this, the Earth viewing systems brightness requirements is required as a function of wavelength.

Once this brightness requirement is determined, the column density of molecules that generate this level can be determined by Dr. D. Torr, UAH. It is anticipated the requirement will be similar in form to that of the stellar viewing systems represented in JSC 30426; ie, that the acceptable contaminant brightness level will be equivalent to the naturally occurring background.

The requirements may have to be subdivided into true earth viewing and earth limb viewing.

3.3 EXCITED MOLECULE DISCRIMINATION

Recent studies show that not all molecules have the same effect in adding to background brightness even if they are the same species. For example, nitrogen from a vent, emitted into free space, is in a different excited state than ambient nitrogen that impacts the vehicle surface and is re-emitted. Therefore, these two sources of nitrogen must be treated differently in their contributions to molecular column densities and resulting brightness. A meeting between Dr. D. Torr and others of the Contamination Workshop participants should be held to further explore this issue.

3.4 Surface Deposition

The deposition rates on surfaces in paragraph 4.5.1.4 of JSC 30426 appear to be overly restrictive for surfaces such as thermal control, solar arrays, radiators, habitation modules, etc.

The allowable levels indicated in JSC 30426, for a flat surface on the truss at 300°K, is 1 x 10^{-14} g cm^{-2} s^{-1}. This equates to a deposition thickness of 30 angstroms per year, roughly equivalent to 10 molecular layers. This level is appropriate for critical UV optics, but appears too restrictive for operational surfaces.

This single required maximum level in JSC-30426 places severe restrictions on all Space Station outgassing rates. Additionally, the Shuttle when docked appears to violate these levels in about one day.

A Contamination Control Working Group should be convened to resolve this and other issues.

3.5 PLASMA REQUIREMENTS

The requirements in JSC-30426 pertain primarily to quiescent payload viewing periods. The only non quiescent period requirement is mentioned in paragraph 4.5.2 and relates to deposition.

Because of high densities from vents or engines, ionizable species or other unique sources can cause plasma perturbations and possible arcing near the solar arrays and other requirements may need to be developed. The non quiescent periods have been assumed (to date) to be times when large quantities of vented material are allowed, as well as engine firings, resistojet operations, unlimited EVA activities, Shuttle docking, etc.

It appears that at least, a density limit on gaseous species at critical locations must be imposed to reduce the chance of detrimental perturbations or arcing.

A coordinated effort between the plasma and contamination working groups should be implemented to resolve this issue.

3.6 QUIESCENT PERIOD DURATION

A requirement in JSC 30426 states "Generally, environment conditions as stated in paragraph 4.5.1 shall be maintained for up to 14 days during required viewing periods".

This was intended to allow attached payload users to have a long period to collect data from a one time event.

It appears this may be overly restrictive on Space Station and would cause cost impacts on the Space Station design to allow storage of all wastes for a 2 week period. Additionally, the use of attitude control engines is expected to be required during nearly every orbit.

Since almost all attached payloads would take data only during a portion of an orbit, the remainder of the orbit could be used for engine firings and vents. Therefore the 14 day period should be modified to minimize Space Station design impacts.

4.0 RECOMMENDED VALUES FOR SELECT CHANGES

Based on data obtained from previous flights and laboratory testing, recommended deposition levels for surfaces such as solar arrays and thermal control are presented in this section.

4.1 SOLAR ARRAY DEPOSITION LEVELS

A spectral extinction coefficient was determined from transmissive optics flown on Gemini XII (Muscari, 1967). The exact nature of these deposits was not determined. The samples were chosen because they represent space flown optics on which a great many measurements were made. The extinction coefficient arrived at is shown in Figure 1. Data available on outgassed deposits and bipropellant engine deposits yields an extinction coefficient that correlates to the data of Figure 1, within 30 to 50%. By applying the spectral extinction coefficient to the spectral response of a solar cell for varying amounts of deposited contaminant, a percent power loss versus deposition can be plotted as shown in Figure 2 (Rantanen, 1974).

The figure shows that solar arrays with a spectral response similar to those used on Skylab will experience near 5% degradation with a deposit of 5000 Å. If the solar array lifetime is 10 years (needs to be determined) before refurbishment, then approximately 500 Å per year is allowed. This relates to approximately 40 Å/yr which is currently given in paragraph 4.5.2.1 in JSC 30426.

Actual allowed degradation and lifetime requirements must be determined before updated allowable deposition levels can be specified. If this data is not available, then a higher deposition level of 500 Å (5×10^{-6} gm cm $^{-2}$) per year is recommended.

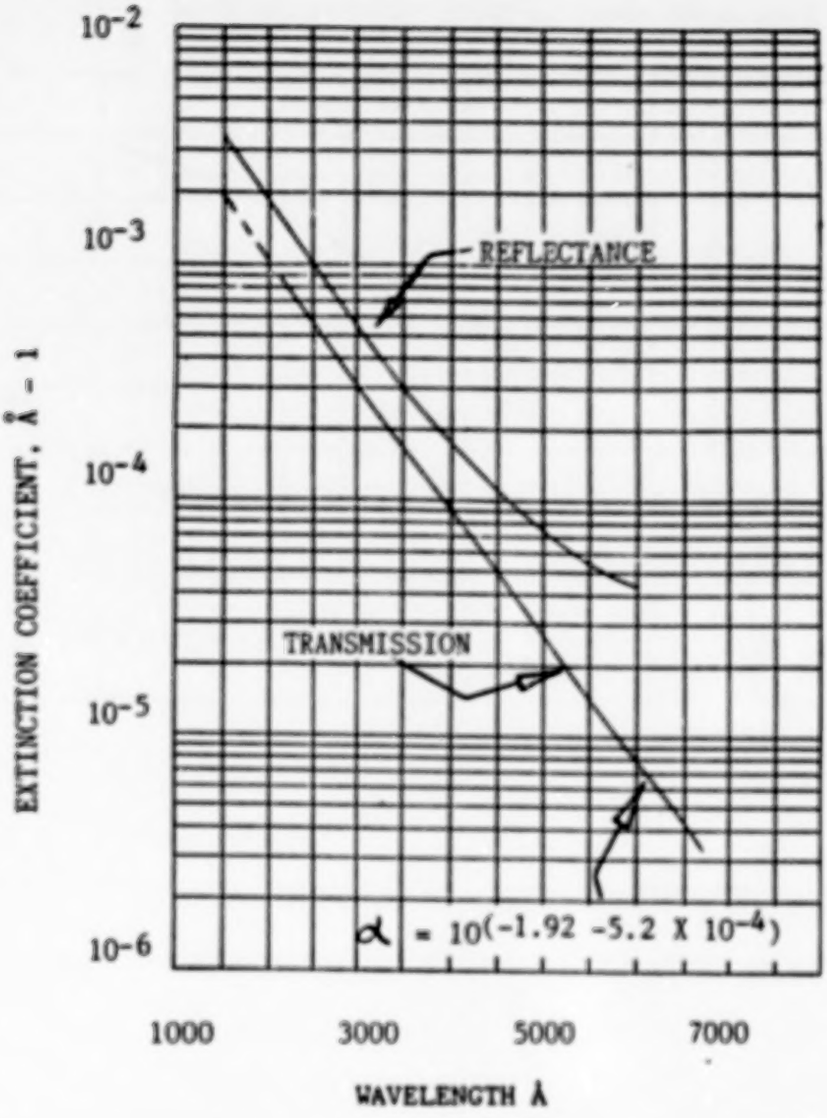

Figure 1. Transmission and reflectance extinction coefficients.

4.2 THERMAL CONTROL SURFACE DEPOSITION LEVELS

Data obtained from Skylab showed changes in solar absorptivity for two types of paint. Samples returned from Skylab were estimated to have particular levels of deposition based on real time deposition monitors on board and model predictions. The samples were exposed to significant levels of solar ultraviolet and were yellow or tan in color. Figure 3 shows the results in change in solar absorptivity versus accumulated deposition for two white paints, Z93 and S13G. The solar absorptivity change allowed will dictate the absorptivity of allowable maximum deposition.

If the allowed absorptivity change due to deposition, over the lifetime of a surface, was 0.1 then the allowable deposition is about 2×10^{-5} gm cm^{-2}, or a thickness of 2000 Å for a unit density deposit.

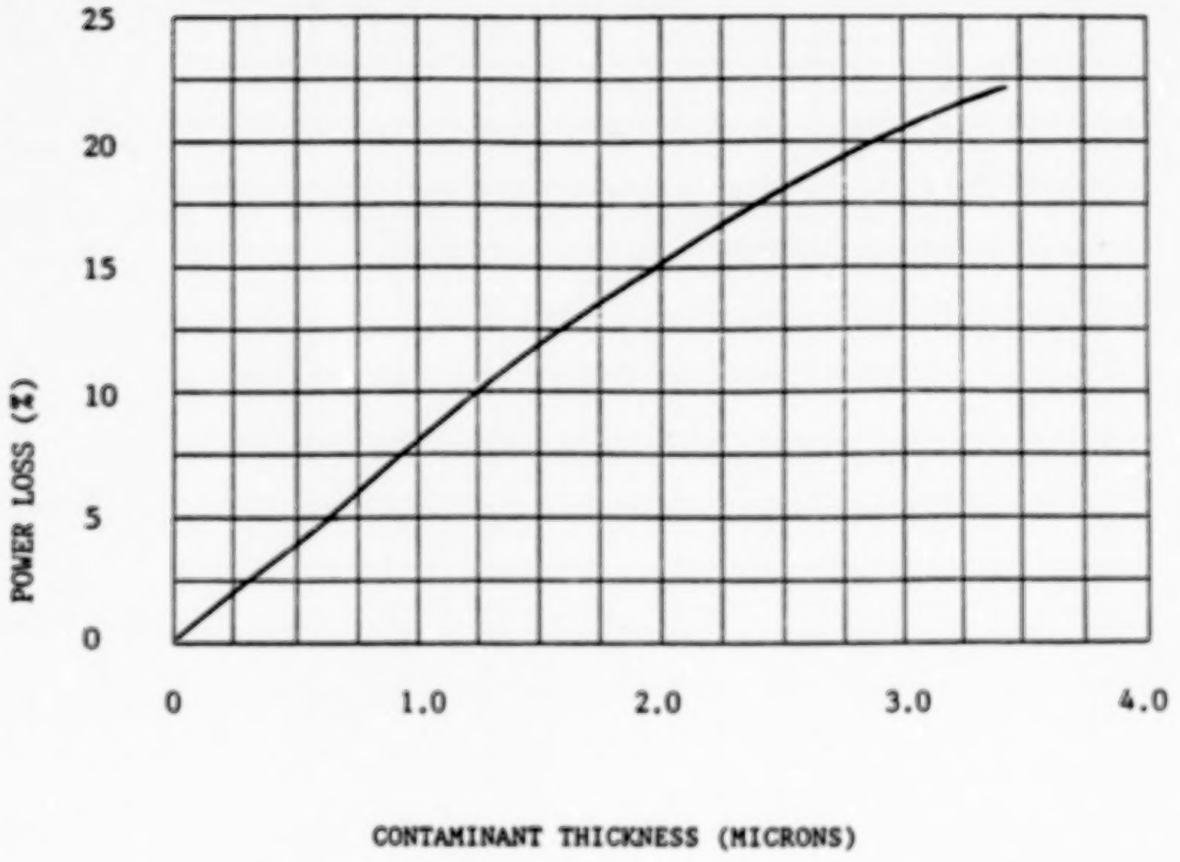

Figure 2. Solar array percent power loss versus deposition.

If these levels are for experiment surfaces on the transverse booms, the actual rate will depend on the total exposure time. For an experiment that resides for 6 months on the truss, the allowed rate would be 1.2×10^{-12} gm cm^{-2} s^{-1}. If, on the other hand, a thermal control surface was exposed for 10 years the allowable 2000 Å would be 6.3×10^{-14} gm cm^{-2} s^{-1}, and if exposed for 30 years, 2×10^{-14} gm cm^{-1} s^{-1}.

Since the truss structure, experiment surfaces, and habitation module exterior will all have different acceptable degradations and lifetime, a range of allowable deposition rates will need to be determined.

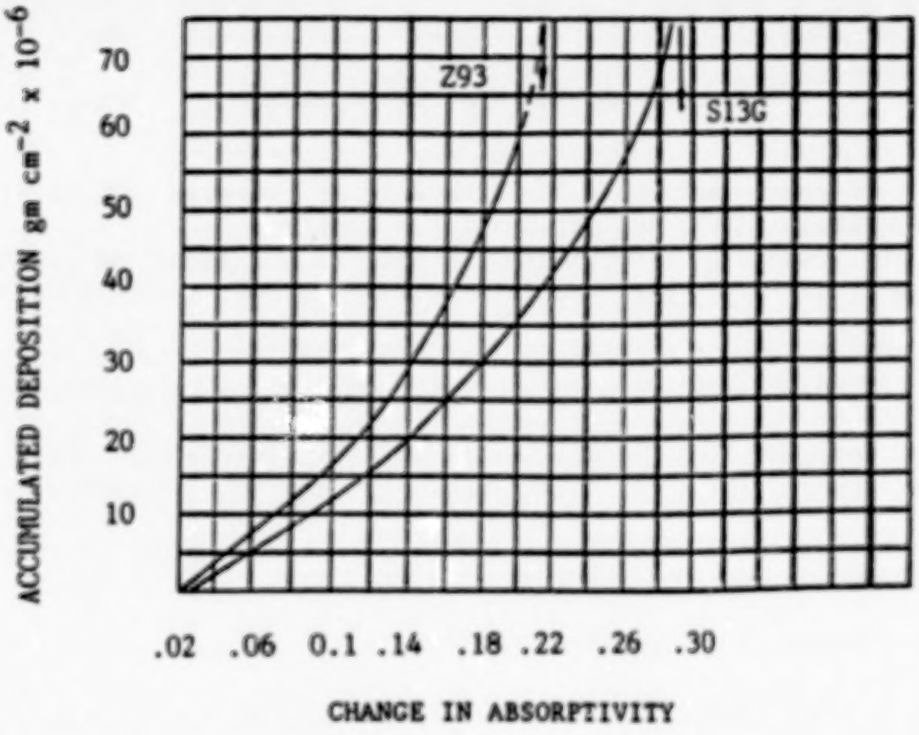

Figure 3. Change in solar absorptivity versus deposited contaminant thickness

Figure 4 shows the solar absorptivity change on S-13G white paint as a result of RCS engine tests at LeRC. Ultraviolet was present during and after deposition. The deposited material in this test should be similar to the deposits from the Shuttle engines. This data shows that the change in solar absorptivity reaches a maximum near 0.1 as compared to 0.3 for the outgassed deposits shown in Figure 3 for S13G.

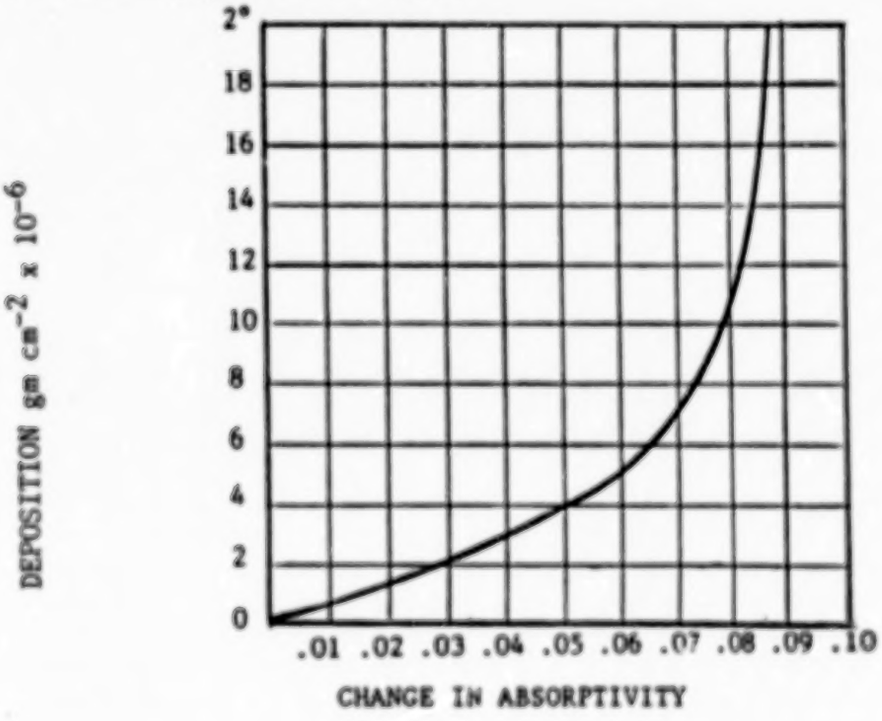

Figure 4. A $\Delta\alpha_s$ change for bipropellant engine exhausts.

5.0 GAS DENSITY NEAR SOLAR ARRAYS

The density of gases near the solar arrays is of interest because of the relatively high voltage (160V) and potential for arcing.

From previous modeling efforts and flowfield analysis of vents and engines, a compilation of gas densities from various sources has been completed.

Table II shows the gas density and the major species involved. Hopefully, this data will aid in determining if there is a potential problem or not.

The density for the vent is calculated on the plume centerline, for a flow rate of 0.1 gm s^{-1} for a 20 meter separation between the vent and the arrays.

The RCS engine calculations are based on a 15 meter separation for both on the plume centerline and at right angles to it.

Table II . Gas densities near solar arrays

SOURCE	MOLECULES/cm^3	SPECIES
RAM PRESSURE	1.2×10^{10}	N_2, O, NO
LEAKAGE	6×10^{8}	H_2, O_2, H_2O
OUTGASSING	8×10^{7}	LARGE ORGANIC MOLECULES
VENT	2×10^{9}	H_2, O, N_2, O_2
RCS (ON AXIS)	6.8×10^{12}	H_2O
RCS (NORMAL TO AXIS)	4.5×10^{9}	H_2O

For normal operating periods, the major contributor is the ambient ram pressure. The RCS engines provide the highest densities, depending on their firing direction relative to the solar panels.

6.0 CONCLUSIONS

The recommended changes presented in this paper should aid both the attached payloads and the Space Station designers. Early implementation of these changes will reduce cost impacts at a later date.

As the Space Station design evolves the contamination control requirements will require revisiting and updating. Changes in altitude and configuration will have the largest impact on contamination if the contamination sources remain comparable.

Continuous analysis and monitoring of the Space Station configuration, operations and potential contamination sources is required to assure an optimum environment for experimentation and research.

A monitoring package is essential to verify compliance, update models, determine experiment environments to assist in data reduction and detect anomalies that occur and would otherwise be unknown. Ideally these monitoring

packages would be directional in nature and would measure surface molecular deposition, identify gas species, measure velocity of gas species, determine surface degradation and detect particulates in space as well as on surfaces.

REFERENCES

Muscari, J.A. and Cunningham, A.C., Gemini XII Contamination Study, Martin Marietta Report R-67-2, 1987.

Rantanen, R.O. and Thornton, J.R., Deposited Contaminants Effect on Solar Array Power Loss, Conference Record of the 10th IEEE Photovoltaics Specialist Conference, 1974, Palo Alto, California, November 13-15, 1973.

N89-15801

Disposition of Recommended Modifications of JSC 30426

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Introduction:

On May 11, 1988 changes and additions to the Space Station External Contamination Control Document JSC 30426 were addressed at length as part of the charter of this workshop. The modifications and disposition thereof are given below in a concise form in order that a clear understanding of the recommendations and current status be presented. The format is that each paragraph under question is given along with the proposed modified paragraph followed by the workshop's disposition. In some cases, a brief explanation of the issue is given prior to the paragraph in question.

Disposition of Recommended Changes to JSC 30426

Paragraph 3.1.1

A two-week quiescent period may be overly restrictive on Space Station resulting in cost impacts on the Space Station design to allow storage of all wastes for that period.

Old: Generally, environment conditions as stated in paragraph 4.5.1 shall be maintained for up to 14 days during required viewing periods.

Suggested New: Quiescent period as stated in paragraph 4.5.1 shall be maintained for 70% of each consecutive orbit during required data take periods for up to 3 days duration.

Disposition: Recommend further study.

Paragraph 4.5.1.1

Insert word "continuum" before each "background" and sentence "Line and band emitting species will have column densities satisfying 4.5.1.2.1".

Old: The total Ultraviolet (UV) and visible radiation background from spacecraft-induced particulate and molecular scattering and emission must be less than the envelope defined by the spectral irradiances in Table 4-1. For the Infrared (IR), the background intensity must be spatially and temporally uniform with a maximum variation of 1.1×10^{-13} watts m^{-2} sr^{-1} nm^{-1} per degree and 5.5×10^{-14} watt m^{-2} sr^{-1} nm^{-1} per second from 5 micrometers to 30 micrometers and 1.1×10^{-12} watt m^{-2} sr^{-1} nm^{-1} per degree and 5.5×10^{-13} watts m^{-2} sr^{-1} nm^{-1} per second above 30 micrometers. To achieve this, the background spectral

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irradiance must be held below the envelope shown in Table 4-2. The maximum allowed value applies only if the background is temporally and spatially uniform enough to meet the stated requirements. The recommended values are based on a best estimate of the anticipated spatial variations.

Suggested New: The total Ultraviolet (UV) and visible radiation continuum background from spacecraft-induced particulate and molecular scattering and emission must be less than the envelope defined by the spectral irradiances in Table 4-1. For the Infrared (IR), the continuum background intensity must be spatially and temporally uniform with a maximum variation of 1.1×10^{-13} watts m^{-2} sr^{-1} nm^{-1} per degree and 5.5×10^{-14} watt m^{-2} sr^{-1} nm^{-1} per degree and 5.5×10^{-13} watts m^{-2} sr^{-1} nm^{-1} per second above 30 micrometers. To achieve this, the continuum background spectral irradiance must be held below the envelope shown in Table 4-2. The maximum allowed value applies only if the continuum background is temporally and spatially uniform enough to meet the stated requirements. The recommended values are based on a best estimate of the anticipated spatial variations. Line and band emitting species will have column densities satisfying 4.5.1.2.1.

Disposition: Recommend implementation.

Paragraph 4.5.1.2.2

The allowable limits in this paragraph should be adjusted to be compatible with Table 4-1.

Old: 1×10^{13} molecules/cm^2 each for O2 for N2, for H2, for noble gases and for all other UV and non-IR active molecules combined (total not to exceed 5×10^{13} molecules/cm^2).

Suggested New: 2×10^{11} molecules/cm^2 each for O2 and N2, for H2, for noble gases and for all other UV and non-IR active molecules combined (total not to exceed 1×10^{12} molecules/cm^2) for any line of sight that is not grazing-incident on a Space Station surface (i.e., main cluster, truss structure, and/or solar panel arrays).

Disposition: Recommend implementation.

Paragraph 4.5.1.3.1

Old: Release of particles from main cluster Space Station shall be limited to one particle 5 microns or larger per orbit per 1×10^{-5} steradian field of view as seen by a 1 meter diameter aperture telescope.

Control of particles less than 5 microns in size shall meet TBD requirements.

Suggested
New: The total ultraviolet, visible and infrared background from spacecraft induced particulates must be less than the background defined by the spectral brightness in Tables 4-1 and 4-2.

Disposition: Recommend implementation.

Paragraph 4.5.1.3.2

Old: TBD

Suggested
New: 4.5.1.3.2A - The particle deposition on surfaces with an acceptance angle of 2π sr shall not exceed 0.5 percent obscuration. 4.5.1.3.2B - The change in BDRF due to particle deposition on surfaces with an acceptance angle of 0.1 sr shall not exceed 50 percent (clean versus contaminated).

Disposition: Recommend clarification and further study.

Paragraph 4.5.1.4

The deposition rates on surfaces may be overly restrictive for surfaces such as thermal control, solar arrays, radiators, habitation modules, etc.

Old: The flux of molecules emanating from the core Space Station must be limited such that:

4.5.1.4.A. The mass deposition rate on two 300 °K surfaces both located at the PMP with one perpendicular to the +Z axis and the other whose surface normal lies in the horizontal plane and at critical power locations with an acceptance angle of 2π steradian shall be no more than 1×10^{-14} g/cm^2 sec (daily average).

4.5.1.4.B. The mass deposition rate on a 300 °K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 1×10^{-16} g/cm^2 sec (daily average).

4.5.1.4.C. The mass deposition rate on a 5 °K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 2×10^{-13} g/cm^2 sec (daily average) excluding condensation of atmospheric constituents.

Suggested
New: 4.5.1.4.A. The mass deposition rate on two critical optical 300 °K surfaces both located at the PMP with one perpendicular to the +Z axis and the other whose surface normal lies in the horizontal plane and at critical power locations with an acceptance angle of 2π steradian, shall be no more than 1×10^{-14} g/cm^2 sec (daily average).

4.5.1.4.B. The mass deposition rate on a critical optical 300 °K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 1×10^{-16} g/cm^2 sec (daily average).

4.5.1.4.C. The mass deposition rate on a 5 °K surface located at the PMP and perpendicular to the Z axis with an acceptance angle of 0.1 steradian shall be no more than 2×10^{-13} g/cm^2 sec (daily average) excluding condensation of atmospheric constituents.

Disposition: Recommend further study.

Paragraph 4.5.1.5

Efforts to anticipate under what conditions arcing and discharges will occur for high-voltage Space Station subsystems indicate potential problems (see following paper by N. Singh). Therefore, the addition of a paragraph 4.5.1.5, labeled Induced Neutral Density is recommended.

Old: N/A

Suggested New: The maximum density of induced neutral species in the vicinity (1 meter) of operating solar arrays shall be less than 10^{10} cm^{-3}.

Disposition: Recommend incorporation.

Paragraph 4.5.2.1

Old: Total deposition on sensitive surfaces such as solar arrays on either the astronomy or Earth resources observation regions shall not exceed 4×10^{-7} g/cm^2 yr.

Suggested New: Total deposition on sensitive surfaces such as the astronomy or Earth resource observation regions shall not exceed 4×10^{-7} g/cm^2 yr. Total deposition on solar arrays shall not exceed 5×10^{-5} gm cm^{-2} over the lifetime of the arrays. Total deposition on external thermal control surfaces shall not exceed 2×10^{-5} gm cm^{-2} over the lifetime of the surfaces.

Disposition: Recommend further study.

Paragraph 4.5.2.2

Old: TBD

Suggested
New: Requirements in 4.5.1.3.2 shall apply during both quiescent and non-quiescent periods.

Disposition: Recommend further study pending clarification of paragraph 4.5.1.3.2.

Paragraph 4.5.2.3

For the same reasons given in Paragraph 4.5.1.5 the following paragraph 4.5.2.3 labeled Induced Neutral Density is recommended as follows.

Old: N/A

Suggested
New: Requirements in Paragraph 4.5.1.5 shall apply during both quiescent and non-quiescent periods.

Disposition: Recommend further study.

Table 4-2.

Old:

TABLE 4-2. INFRARED BACKGROUND SPECTRAL IRRADIANCE

WAVELENGTH (Micrometers)	RECOMMENDED SPECIAL IRRADIANCE (watts m^{-2} sr^{-1} nm^{-1})	MAXIMUM SPECTRAL IRRADIANCE (UNIFORM BACKGROUND) (watt m^{-2} sr^{-1} nm^{-1})
1	1.0×10^{-10}	1.0×10^{-10}
5	5.0×10^{-11}	1.0×10^{-10}
10	4.0×10^{-11}	2.0×10^{-10}
<30	1.0×10^{-11}	4.0×10^{-11}
>30	6.0×10^{-12}	3.0×10^{-11}
300	3.0×10^{-13}	1.0×10^{-11}

Suggested
New:

TABLE 4-2. INFRARED CONTINUUM BACKGROUND SPECTRAL IRRADIANCE

WAVELENGTH (Micrometers)	RECOMMENDED SPECIAL IRRADIANCE (watts m^{-2} sr^{-1} nm^{-1})	MAXIMUM SPECTRAL IRRADIANCE (UNIFORM BACKGROUND) (watt m^{-2} sr^{-1} nm^{-1})
1 - 3	1.0×10^{-10}	1.0×10^{-10}
3 - 7	5.0×10^{-11}	1.0×10^{-10}
7 - 15	4.0×10^{-11}	2.0×10^{-10}
15 - 30	1.0×10^{-11}	4.0×10^{-11}
30 - 200	6.0×10^{-12}	3.0×10^{-11}
200 - 500	3.0×10^{-13}	1.0×10^{-11}

Disposition: Recommend implementation.

N89-15802

Arcing and Discharges in High–Voltage Subsystems of Space Station

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Abstract

Arcing and other types of electrical discharges are likely to occur in high–voltage subsystems of the Space Station. Results from ground and space experiments on the arcing of solar cell arrays are briefly reviewed, showing that the arcing occurs when the conducting interconnects in the arrays are at negative potential above a threshold, which decreases with the increasing plasma density. Furthermore, above the threshold voltage the arcing rate increases with the plasma density. At the expected operating voltages (~200V) in the solar array for the space station, arcing is expected to occur even in the ambient ionospheric plasma. If the ionization of the contaminants increases the plasma density near the high–voltage systems, the adverse effects of arcing on the solar arrays and the space stations are likely to be enhanced. In addition to arcing, other discharge processes are likely to occur in high–voltage subsystems. For example, Paschen discharge is likely to occur when the neutral density $N_n > 10^{12}$ cm^{-3}, the corresponding neutral pressure $P > 3 \times 10^{-5}$ Torr.

1. Introduction

The purpose of this paper is to report on the possible effects of contaminant gases on the arcing and other discharge processes occurring near Space Station subsystems operating at relatively high voltages. The subsystem which is of primary concern here is the solar cell array, which is the heart of the Space Station Power System (SSPS). Under normal operating conditions the SSPS will operate at 160V, but during the cold starts the operating voltage is likely to double to about 320V. One of the main concerns here is, whether or not, at such voltages arcing and other discharge processes will occur in the array. These processes are likely to produce several unwanted effects on the power system and the space station, some of which are: (i) degradation of the solar cells, (ii) transients in the power system, even leading to the power disruptions, and (iii) electromagnetic interference, which can be detrimental to communications and telemetry.

In the following section we briefly review the existing knowledge on arcing in solar cell arrays and then we use it to predict the allowable contaminant densities near the arrays.

2. Arcing in Solar Cell Array

The information on arcing in solar cell arrays has been obtained from both ground and space–flight tests. However, the latter tests are limited to only two flights known as

PIX–1 and PIX–2, where PIX stands for Plasma Interaction Experiments. Results from both ground–based and space–flight experiments have been summarized by Stevens [1986], and Ferguson [1986] and Purvis et al [1988]. Some of the questions which have been attempted to be resolved using the experimental data are as follows: (i) Is there a voltage threshold for arcing? (ii) How does this threshold vary with the local plasma density?, (iii) How does the arcing rate for voltages above the threshold vary with the plasma density and other plasma parameters?

Figure 1 shows a summary plot of threshold potential as a function of the ambient plasma density. PIX–1 data are limited and they show that arcs occur at potentials between –700 and –1000 volts for all plasma densities [Purvis et al, 1988]. On the other hand, the more complete PIX–2 data set shows that threshold voltage decreases with the increasing plasma density. Furthermore, a comparison of the ground test data with the PIX–2 data shows that both the data sets predict the general trend of decreasing threshold voltage with the increasing plasma density, but the threshold voltages for the former set are higher than those for the latter data set based on space experiments.

The above conclusion drawn regarding the arcing threshold voltage is based on a very limited data set. Unfortunately, there are no theoretical basis so that the applicability of the data set can be extended to conditions for which the measurements have not been performed.

We use here PIX–2 data to decide whether there is a possibility of arcing in Space Station solar cell arrays. Barring transients, and cold starts after eclipse, the maximum voltage on solar cells will be near –160 volts, for which arcing is likely to occur at densities $N > 2 \times 10^5$ cm^{-3} (see Fig. 1).

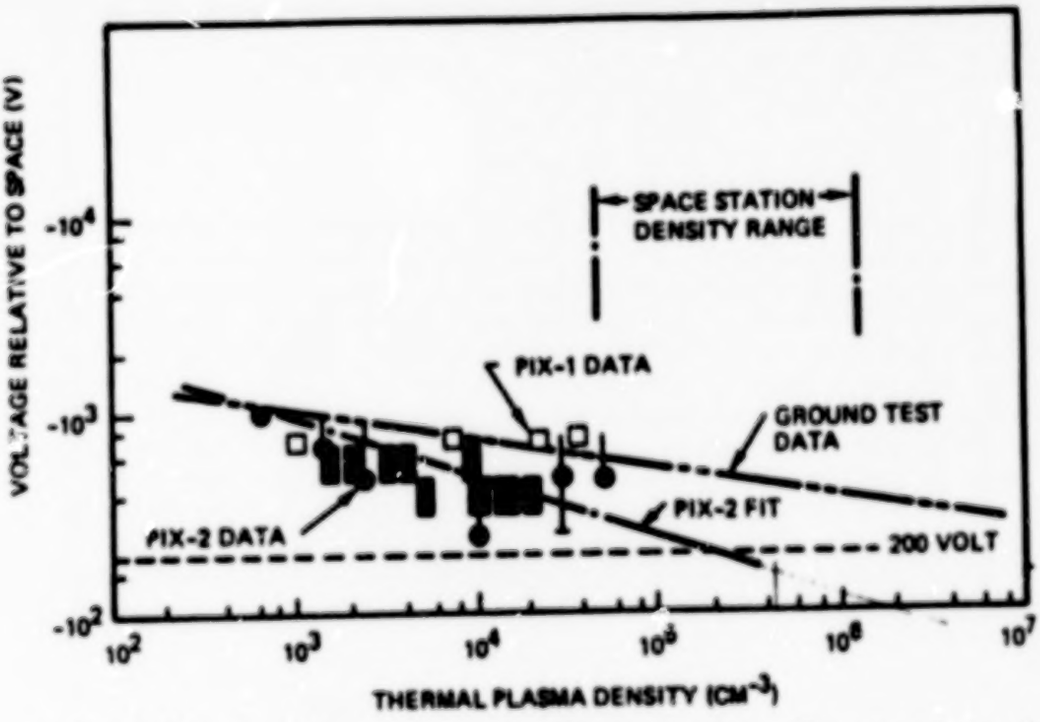

Fig. 1. Threshold voltage for arcing versus plasma density. The ground test data show a higher threshold than the PIX–2 data from a flight experiment (Steven, 1986).

In the altitude range of the space station the ambient plasma density is likely to be in the range $10^4 - 10^6$ cm^{-3}, indicating the possibility of arcing even in the ambient plasma. The ionization of the contaminant molecules and atoms is likely to increase the plasma density above the ambient density. This may further aggravate the arcing problem.

The contaminant molecules and atoms are generated by outgassing, leakage, venting and thruster firings. In addition, the phenomenon of ram pile–up enhances the neutral density in front of the vehicle. This enhancement can be as large as 20 times the ambient neutral density.

The neutral densities of the contaminants and that associated with the ram pile–up have been calculated by the Science and Engineering Associates (SEA) contamination model [Rantanen, 1988]. For example, Table 1 shows the total density of the neutrals in the ambient environment and the enhanced density due to the ram pile–up.

The production of plasma from the neutrals depends on the efficiency of the ionization processes, which include photoionization and charge exchange processes, and also on the transport of plasma. Thus, the determination of the total plasma density around the vehicle is a difficult task. However, at the altitude range of the space station it can be roughly assumed that about one out of 10^4 molecules or atoms are ionized. Thus, the ram plasma density can be as high as 10^7 or more and Fig. 1 shows that arcing is quite likely to occur.

Since the solar arrays for the space station are likely to have very large surface areas, the ram effects can be very pronounced. Thus, if the solar cells are exposed to the ram plasma, the arcing is expected to occur at smaller voltages (and over a larger portion of the array) than those at which the solar cells arc in the ambient plasma.

Recent analysis of data from both ground and space experiments show that the arcing rate (R) depends on the plasma properties as follows [Ferguson, 1986]:

$$R \propto n(T/m)^{1\backslash 2} \tag{1}$$

where n and T are the plasma density and (ion) temperature, respectively, and m is the ion mass. The proportionally constant and the dependence on the voltage is found to vary from one set of experiments to another. From space data, it is empirically found that

$$R \simeq 2.8 * 10^{-13} |V|^{3.1} n(T/m)^{1\backslash 2} \tag{2}$$

where V is in volts, n is in cm^{-3}, T is in eV and m in amu. The above relation is found to be true above a threshold at about –230V. However, this threshold is true for the prevalent ionospheric plasma densities. When the plasma density is enhanced either by ionization of the contaminants or by ram pile–up the threshold is likely to be reduced and the arc rate is likely to go up. However, a quantitative estimate of the plasma density enhancement associated with the enhancement in the neutral density remains an unsolved problem, and its solution must include both ionization and transport processes.

There is another issue involved here dealing with the effect of neutrals on the high voltage systems. At very low pressures nearing vacuum conditions discharges are difficult to occur. However, when the pressure increases so that the mean free path for the electron collision with the neutrals become of the order of the inter–electrode spacing d, the Paschen discharge occurs. For the Space Station sub–systems at high voltages the inter–electrode spacing is roughly the sheath size, which is roughly of the order of 10 cm or so at the voltages of about hundred volts. Thus, the condition for Paschen discharge becomes

$$N_n > \frac{1}{d\sigma} \tag{3}$$

where σ is the collision cross section. Since the molecule size r >> size of an electron, $\sigma \simeq \Pi ir^2$. Assuming $r \simeq 3 \times 10^{-9}$m, we find

$$N_n > 10^{12}\ cm^{-3} \tag{4}$$

This neutral density amounts to a neutral pressure $> 3 \times 10^{-5}$ torr, which is two order of magnitudes or more larger than the ambient neutral pressure. But such enhancements of the neutral pressure have been observed aboard space shuttle during thruster firings [Wulf, 1986].

Since Paschen discharge and associated plasma processes may lead to arcing, it is recommended that neutral pressure must be controlled to $< 10^{-5}$ torr or equivalently $N_n < 10^{12}\ cm^{-3}$.

3. Summary

At the operating voltages for the space station solar cell arrays, arcing is expected to occur even with the ambient plasma. If the plasma density is enhanced by the ionization of the contaminants, the voltage threshold for arcs is likely to be reduced, causing arcing over a larger portion of the array. Furthermore, the arcing rate goes up with the plasma density. Thus, the detrimental effects of arcing on the array and the space station are likely to be enhanced by increase in the plasma density due to the ionization of the contaminants.

High neutral densities ($N_n > 10^{12}\ cm^{-3}$) near high voltage systems are likely to cause discharge processes other than arcing. Such discharges generate plasma and are likely to create conditions for increased arcing. The ram pile–up (Table 1) at low altitudes (~200 km) appears to generate neutral densities comparable to this value.

Finally, we state that our theoretical understanding of arcing and discharges is far from complete. Thus, it becomes very difficult to draw general conclusions from the limited set of data from laboratory and space tests on arcing of solar cell arrays. It is recommended that systematic investigations involving both theory and experiments be carried out so that arrays characterizations be carried out with confidence. Such an investigation warrants a global model of space station based on generation and transport of both neutrals and plasma

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16. ABSTRACT

This report contains the results of a conference convened May 10-11, 1988, to review plans for monitoring the Space Station induced environment, to recommend primary components of an induced environment monitoring package, and to make recommendations pertaining to suggested modifications of the Space Station External Contamination Control Requirements Document #JSC 30426. The contents of this report are divided as follows:

- Monitoring Induced Environment
  - Space Station Work Packages Requirements
  - Neutral Environment
  - Photon Emission Environment
  - Particulate Environment
  - Surface Deposition/Contamination
- Contamination Control Requirements

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